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Gloucester and Avon Rivers Flood Study

Final Report

R.N20257.001.02, April 2015

Gloucester Shire Council

Gloucester and Avon Rivers Flood Study

Prepared for:	Gloucester Shire Council
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

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Executive Summary

Introduction

The Gloucester and Avon Rivers Flood Study has been prepared for Gloucester Shire Council (Council) to define the existing flood behaviour in the catchment and establish the basis for subsequent floodplain management activities.

This project has been implemented through the Gloucester Water Study Project.

The primary objective of the Flood Study is to define the flood behaviour within the Gloucester and Avon Rivers catchment through the establishment of appropriate numerical models. The study has produced information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment and floodplain conditions. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design event including the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF event; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

Catchment Description

The town of Gloucester sits between the Gloucester and Avon Rivers and is located around 1km upstream of their confluence. The Barrington River joins the Gloucester River around 1km downstream of the Avon River confluence. The Gloucester, Avon and Barrington Rivers form part of the broader Manning River catchment on the NSW mid-north coast.

The Avon River catchment is some 290km^2 in size. It has a few major tributaries and the catchment topography is relatively flat compared to the Gloucester and Barrington catchments. Mining activity in the south of the catchment may also have some influence on the catchment flood hydrology.

The Gloucester River catchment is some 250km^2 in size upstream of Gloucester and is principally one major watercourse with a long, narrow catchment. The catchment is steeper than that of the Avon River, rising in the Gloucester Tops, which is elevated above 1200m AHD.

The Barrington River catchment is some 700km^2 in size and consists of a number of major tributaries draining the eastern slopes of the Barrington Tops. These form three rivers – the Cobark, Barrington and Kerripit – that join at a single confluence location. This configuration has the potential to generate significant flood flows and subsequent elevated tailwater conditions along the Gloucester River from the Barrington River confluence.

Land use within the catchment primarily consists of forested areas, comprising 70% of the Barrington catchment, 60% of the Gloucester catchment and 65% of the Avon catchment. The remaining land uses are predominantly pastureland and other cultivated areas.

The township of Gloucester is the main community within the catchment, with a population of around 2,500. The much smaller communities of Stratford and Barrington are the other main population centres in the study catchments.

The two main transport routes that traverse the area are the Bucketts Way (connecting Gloucester with Taree 50km to the east and Newcastle 100km to the south) and the Thunderbolts Way (connecting Gloucester with Armidale 170km to the north). The north coast railway also traverses the study area, connecting Maitland to Taree (via Dungog and Gloucester) and the north coast beyond. These transport routes cross the floodplains of the Gloucester, Avon and Barrington Rivers. They may both impact the flood behaviour and/or be impacted by flooding.

Historical Flooding

Significant flooding has occurred in the catchment since records began some 150 years ago. The February 1929 flood is the largest on record, reaching a likely level of around 93m AHD on the Gloucester River at Gloucester. Since official gauged records began in 1952 there have been a number of significant flood events. Three large events occurred in the 1950s, the largest of which was in 1956, measuring 91.85m AHD at the Gloucester gauge. The 1970s also saw a number of large flood events, peaking at 90.52m AHD in 1978. After a relatively flood-free period throughout the 1980s and 1990s the 21st century has seen a number of notable flood events, the most significant of which occurred in 2011 and measured 90.39m AHD at the Gloucester gauge.

Community Consultation

Community consultation has been an important component of the current study. The consultation has aimed to inform the community about the development of the flood study and its likely outcome as a precursor to subsequent floodplain management activities. It has provided an opportunity to collect information on their flood experience and their concerns on flooding issues.

The key elements of the consultation process have been as follows:

- Production of a community information brochure providing information on the study;
- Distribution of a questionnaire to landowners, residents and businesses within the study area;
- An information session for the community to present information on the progress and objectives of the flood study and obtain feedback on historical events in the catchment and other flooding issues; and
- Public exhibition of the draft Flood Study.

Model Development

Development of hydrologic and hydraulic models has been undertaken to simulate flood conditions in the catchment. The hydrological model developed using XP-RAFTS software provides for simulation of the rainfall-runoff process using the catchment characteristics of the Gloucester River and historical and design rainfall data. The hydraulic model, simulating flood depths, extents and velocities utilises the TUFLOW two-dimensional (2D) software developed by BMT WBM. The 2D modelling approach is suited to model the complex interaction between channels and floodplains and converging and diverging of flows through structures and urban environments.

The floodplain topography is defined using a digital elevation model (DEM) derived from aerial survey data provided by Council. An analysis of the aerial survey was undertaken to derive representative channel bed elevations for the major watercourses. This was then validated against available topographic survey data.

With consideration to the available survey information and local topographical and hydraulic controls, a 2D model was developed extending from downstream of the Barrington and Gloucester Rivers' confluence, upstream along the major tributary routes. The model extends along the Gloucester and Barrington Rivers to the Forbesdale gauge sites. The majority of the Avon River floodplain is also incorporated. The area modelled within the 2D domain comprises a total area of some 220 km^2 of the catchment (approximately 18% of total catchment area).

Model Calibration and Validation

The selection of suitable historical events for calibration of computer models is largely dependent on available historical flood information. Ideally the calibration and validation process should cover a range of flood magnitudes to demonstrate the suitability of a model for the range of design event magnitudes to be considered.

Since records began in 1952, the two largest floods experienced in Gloucester occurred in 1956 and 1978. Due to the scarcity of calibration data available for these events, notably any continuous rainfall records to appropriately define temporal patterns of storms and stream flow gauges to compare discharge rates, there was need to select a more recent event where sufficient calibration data was available.

The June 2011 flood event is the largest of the significant recent events to have occurred within the study area. Given the abundance of data available for model inputs and calibration, particularly within the Avon River catchment, as detailed in a number of recent studies within the area, it has been selected as the principal calibration event for the models. The February 2013 also generated a reasonable flood response within the catchment but was not as large as that in June 2011. It has also been selected for model calibration given the relative availability of data.

The February 1929 event was the largest flood known to have occurred within the Gloucester township. Given there is reasonable coverage of historical data available for this event, in the form of recorded flood levels, daily rainfall data, historical photographs and anecdotal evidence, this was selected as a further validation event.

Design Event Modelling and Output

The developed models have been applied to derive design flood conditions within the Gloucester and Avon River catchments. For the study catchments, design floods were based on a combination of flood frequency and design rainfall estimates in accordance with the procedures Australian Rainfall and Runoff (IEAust, 2001).

The design events considered in this study include the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF events. The model results for the design events considered have been presented in a detailed flood mapping series for the catchment (see separate Mapping Compendium). The flood data presented includes design flood inundation, peak flood water levels and depths and peak flood velocities.

Provisional flood hazard categorisation in accordance with Figure L2 of the NSW Floodplain Development Manual (2005) has been mapped in addition to the hydraulic categories (floodway, flood fringe and flood storage) for flood affected areas.

Sensitivity Testing

A number of sensitivity tests have been undertaken to identify the impacts of the adopted model conditions on the design flood levels. Sensitivity tests included:

- The impact of potential future climate change, including increased rainfall intensities;
- Changes in the adopted roughness parameters;
- Changes in the modelled channel bed profiles; and
- Hydraulic structure blockages.

Floodplain Risk Management Considerations

The study will provide updated and more detailed flooding information to support the existing Gloucester Floodplain Management Study. As such some floodplain risk management considerations were included within this study.

A flood damages assessment was undertaken using the available property floor level survey and design flood modelling outputs. Damages were considered for the residential, commercial and caravan park properties and for damages to public utilities. The derivation of Average Annual Damages enables a basis to assess potential future floodplain risk management options in the catchment.

The Flood Planning Level was derived from the design 1% AEP flood level surface and the application of a 0.5m freeboard allowance. This level was used to map the Flood Planning Area in which flood planning controls are applicable to future development.

Additional information was provided to inform flood emergency response planning within the catchment. This included an assessment of flood warning, flooding of evacuation routes and major access routes. The SES guidelines were also used to define appropriate flood classification of communities. These emergency response aspects were taken into consideration to define true hazard categorisation mapping for the study area.

Conclusions

The objective of the study was to undertake a detailed flood study of the Gloucester and Avon River catchments and establish models as necessary for design flood level prediction.

In completing the flood study, the following activities were undertaken:

- Collation of historical and recent flood information for the study area;
- Development of computer models to simulate hydrology and flood behaviour in the catchment;

- Calibration of the developed models using the available flood data, including the recent events of 2011 and 2013 and the historic events of 1929, 1956 and 1978;
- Prediction of design flood conditions in the catchment and production of design flood mapping series.

The main departure of this study from the previous work is the significant reduction in flood level estimations for the more frequent flood events. This is primarily a function of the design rainfall depths which were adopted for the hydrologic modelling. This study included flood frequency analyses at the Forbesdale gauges on the Gloucester and Barrington Rivers, which determined that the more frequent flood events were significantly over estimated by the standard rainfall runoff approach.

The modelled flood level in Gloucester for the 1% AEP event is similar in this study to that of the previous modelling (and to that of the 1929 flood). This event is used as the basis for flood planning controls and so the updated flood mapping should provide a relative consistency with what has previously been used for these purposes.

As was determined through the previous studies, the majority of flood risk within Gloucester is associated with the commercial and residential properties situated between The Billabong and Church Street. There is limited flooding to other properties outside of this area except in the PMF. The caravan park requires evacuation prior to the onset of flooding as it is situated on an island that becomes isolated by floodwaters.

Acknowledgements

Gloucester Shire Council would like to acknowledge the following organisations for assistance in preparation of the Gloucester and Avon Rivers Flood Study:

- Bruce Sun, Local Controller Gloucester NSW State Emergency Service, for assistance in site inspections, provision of flood photographs and information regarding the history of the Gloucester gauging station;
- Gloucester and District Historical Society for provision of historical photos;
- Residents of the Gloucester, Avon and Barrington River catchments that participated in the Community Questionnaire; and
- AGL Upstream Investments and Gloucester Resources Limited for provision of data from private stream gauging networks and LiDAR survey.

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Glossary

annual exceedance probability (AEP)	AEP (measured as a percentage) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year. For example, a 1% AEP flood is a flood that has a 1% chance of occurring, or being exceeded, in any one year. It is also referred to as the '100 year ARI flood' or '1 in 100 year flood'. The term 100 year ARI flood has been used in this study. See also average recurrence interval (ARI).
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
attenuation	Weakening in force or intensity
average recurrence interval (ARI)	ARI (measured in years) is a term used to describe flood size. It is the long-term average number of years between floods of a certain magnitude. For example, a 100 year ARI flood is a flood that occurs or is exceeded on average once every 100 years. The term 100 year ARI flood has been used in this study. See also annual exceedance probability (AEP).
catchment	The catchment at a particular point is the area of land that drains to that point.
design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).
development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
flood	A relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood behaviour	The pattern / characteristics / nature of a flood.
flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
flood hazard	The potential for damage to property or risk to persons during a flood. Flood hazard is a key tool used to determine flood severity and is used for assessing the suitability of future types of land use.The degree of flood hazard varies with circumstances across the full range of floods.

flood level	The height of the flood described either as a depth of water above a particular location (eg. 1m above a floor, yard or road) or as a depth of water related to a standard level such as Australian Height Datum (eg the flood level was 7.8 mAHD). Terms also used include flood stage and water level.
flood liable land	see flood prone land
floodplain	Land susceptible to flooding up to the probable maximum flood (PMF). Also called flood prone land. Note that the term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level.
floodplain risk management study	Studies carried out in accordance with the Floodplain Development Manual (NSW Government, 2005) that assesses options for minimising the danger to life and property during floods. These measures, referred to as ‘floodplain risk management measures / options’, aim to achieve an equitable balance between environmental, social, economic, financial and engineering considerations. The outcome of a Floodplain Risk Management Study is a Floodplain Risk Management Plan.
floodplain risk management plan	The outcome of a Floodplain Risk Management Study.
flood planning levels (FPL)	The combination of flood levels and freeboards selected for planning purposes, as determined in Floodplain Risk Management Studies and incorporated in Floodplain Risk Management Plans. The concept of flood planning levels supersedes the designated flood or the flood standard used in earlier studies..
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
flood stage	See flood level.
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
flood study	A study that investigates flood behaviour, including identification of flood extents, flood levels and flood velocities for a range of flood sizes.
floodway	Those areas of the floodplain where a significant discharge of water occurs during floods. Floodways are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.

freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determing the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
high flood hazard	For a particular size flood, there would be a possible danger to personal safety, able-bodied adults would have difficulty wading to safety, evacuation by trucks would be difficult and there would be a potential for significant structural damage to buildings.
hydraulics	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrology	The term given to the study of the rainfall-runoff process in catchments.
low flood hazard	For a particular size flood, able-bodied adults would generally have little difficulty wading and trucks could be used to evacuate people and their possessions should it be necessary.
m AHD	metres Australian Height Datum (AHD).
m/s	metres per second. Unit used to describe the velocity of floodwaters.
m^3/s	Cubic metres per second or ‘cumecs’. A unit of measurement for creek or river flows or discharges. It is the rate of flow of water measured in terms of volume per unit time.
overland flow path	The path that floodwaters can follow if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads. Floodwaters travelling along overland flow paths, often referred to as ‘overland flows’, may or may not re-enter the main channel from which they left; they may be diverted to another water course.
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
probable maximum flood (PMF)	The largest flood likely to ever occur. The PMF defines the extent of flood prone land or flood liable land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF event are addressed in the current study.
probability	A statistical measure of the likely frequency or occurrence of flooding.
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.

stage	See flood level.
topography	The shape of the surface features of land
velocity	The term used to describe speed of floodwaters, usually in m/s.
water level	See flood level.

1 Introduction

The Gloucester and Avon Rivers Flood Study has been prepared for Gloucester Shire Council (Council) to define the existing flood behaviour in the catchment and establish the basis for subsequent floodplain management activities.

This project has been implemented through the Gloucester Water Study Project.

1.1 Study Location

The Gloucester and Avon River catchments encompass an area of approximately 550km^2 downstream to the confluence of the two rivers, of which around 290km^2 forms the Avon River catchment. The Barrington River joins the Gloucester River around 1km downstream of the Avon River confluence, providing a further 700km^2 of contributing catchment area. The Gloucester, Avon and Barrington Rivers form part of the broader Manning River catchment, which is over 8,000km^2 in size and drains to the Tasman Sea on the NSW mid-north coast as shown in Figure 1-1.

The township of Gloucester is the main community within the Gloucester River catchment. It is situated between the Gloucester and Avon Rivers, around 1km to the south of their confluence. Much of the study area is occupied by rural pasture lands.

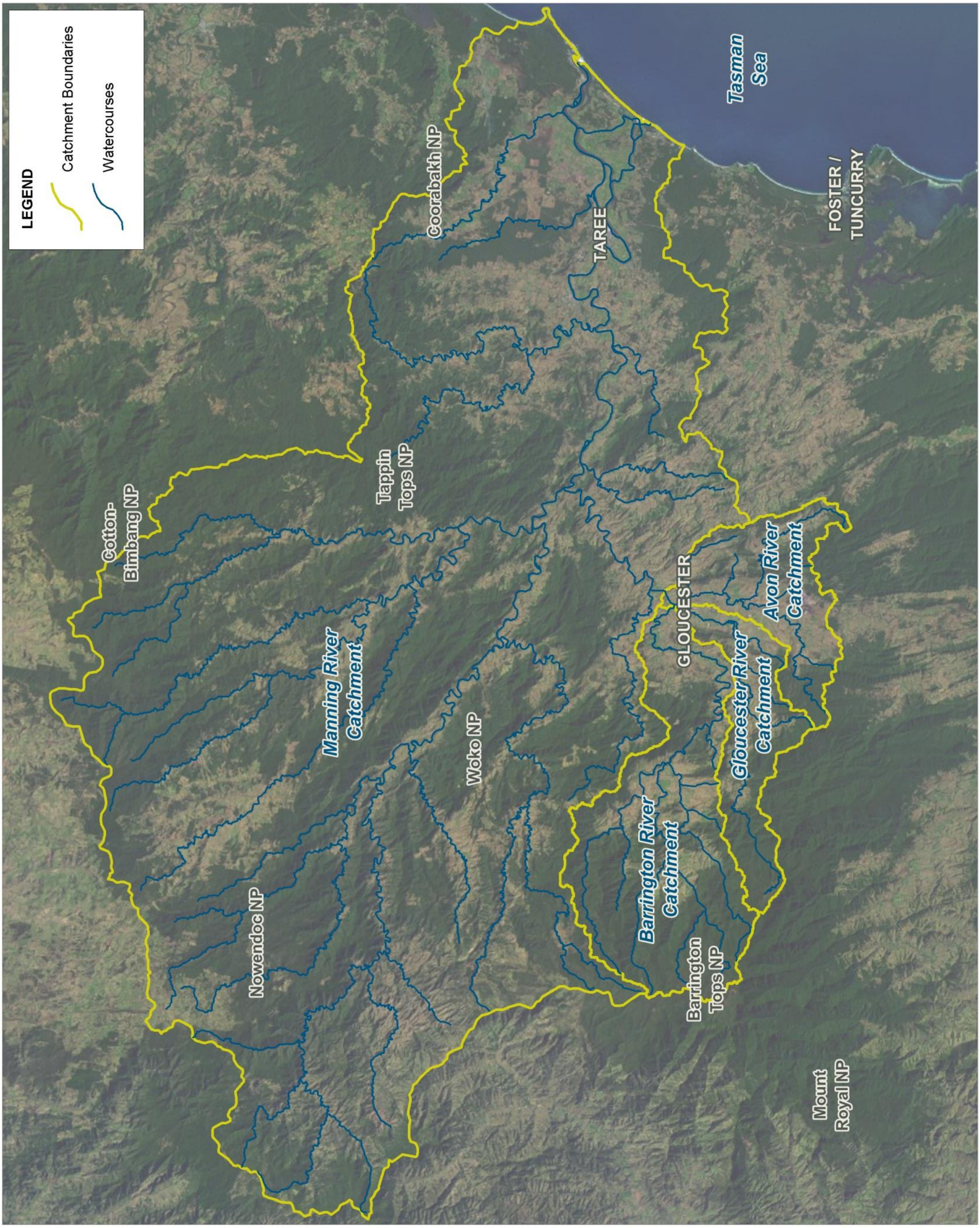
1.2 Study Background

Detailed studies of the flood behaviour within the study catchment have previously been undertaken. These studies culminated in the Gloucester Flood Study Supplementary Report and Gloucester Floodplain Management Study in 2004. The previous studies were focussed principally on the town of Gloucester. Funding was obtained through the Gloucester Water Study Project to undertake a detailed flood study of the broader area, expanding the study area to incorporate the Avon River catchment.

The Gloucester Water Study Project (the Water Study) is a set of independent projects that are intended to provide the Gloucester community with technical information relating to coal seam gas extraction in the region in the context of the AGL Gloucester Gas Project. The Water Study focusses on water management and flooding within the catchments, as well as providing landholders with baseline water quality monitoring on their properties, and undertaking technical peer reviews of AGL's documents.

In addition to extending the previous area of flood investigation, the Water Study enables improvement of the existing flooding information for Gloucester. Advances in technology in the decade since the completion of the previous studies allow a much more detailed representation of the floodplain and significantly improve the quality of mapping output. This provides a more detailed and comprehensive dataset from which to make informed floodplain management decisions.

Significant flooding has occurred in the catchment since records began some 150 years ago. The February 1929 flood is the largest on record, with more recent flooding occurring in March 1956 and March 1978. After a relatively flood-free period throughout the 1980s and 1990s the 21st century has seen a number of notable flood events, the most significant of which occurred in 2011.



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1.3 The Need for Floodplain Risk Management in the Gloucester and Avon Rivers

A Floodplain Risk Management Plan was recently completed for Gloucester in 2004. However, the availability of funding has enabled a new Flood Study to be undertaken. There have been significant developments in hydraulic modelling since the previous studies. The opportunity to undertake a new study will provide improvements to the existing flooding information, particularly with regards to the flood mapping outputs. These will help guide both the floodplain risk management and emergency response management processes.

1.4 The Floodplain Risk Management Process

The State Government's Flood Prone Land Policy is directed towards providing solutions to existing flooding problems in developed areas and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. Policy and practice are defined in the Floodplain Development Manual.

Under the Policy the management of flood liable land remains the responsibility of Local Government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the State Government through the following four sequential stages:

Table 1-1 Stages of Floodplain Risk Management

	Stage	Description
1	Formation of a Committee	Established by Council and includes community group representatives and State agency specialists.
2	Data Collection	Past data such as flood levels, rainfall records, land use, soil types etc.
3	**Flood Study**	**Determines the nature and extent of the flood problem.**
4	Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed developments.
5	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of risk management for the floodplain.
6	Implementation of the Floodplain Risk Management Plan	Construction of flood mitigation works to protect existing development. Use of environmental plans to ensure new development is compatible with the flood hazard.

This study represents Stage 3 of the above process and aims to provide an understanding of flood behaviour within the Gloucester and Avon Rivers catchment. It also includes elements typically undertaken at Stage 4.

1.5 Study Objectives

The primary objective of the Flood Study is to define the flood behaviour within the Gloucester and Avon Rivers catchment through the establishment of appropriate numerical models. The study has produced information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment and floodplain conditions. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design event including the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF event; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

The principal outcome of the flood study is the understanding of flood behaviour in the catchment and in particular design flood level information that will be used to set appropriate flood planning levels for the study area.

1.6 About this Report

This report documents the Study's objectives, results and recommendations.

Section 1 introduces the study.

Section 2 provides an overview of the approach adopted to complete the study.

Section 3 outlines the community consultation program undertaken.

Section 4 provides information on the additional survey collected for this study.

Section 5 details the development of the computer models.

Section 6 details the model calibration and validation process including sensitivity tests.

Section 7 presents the adopted design flood inputs and boundary conditions.

Section 8 presents design flood simulation results and associated flood mapping.

Section 9 presents floodplain risk management considerations.

2 Study Approach

2.1 The Study Area

2.1.1 Catchment Description

The town of Gloucester sits between the Gloucester and Avon Rivers and is located around 1km upstream of their confluence. The Barrington River joins the Gloucester River around 1km downstream of the Avon River confluence. Large flood events on the Barrington River are understood to impact on the flood conditions within the lower reaches of the Gloucester and Avon Rivers and therefore also needs to be considered as part of a comprehensive study on flood behaviour in Gloucester. The Gloucester, Avon and Barrington Rivers form part of the broader Manning River catchment on the NSW mid-north coast.

The topography of the study catchments is shown in Figure 2-1. From a high elevation of around 1500m AHD on the Barrington and Gloucester Tops plateau, the topography grades steeply from the upper slopes to the floodplain areas surrounding Gloucester (at under 100m AHD).

The Avon River catchment is some 290km^2 in size. It has a few major tributaries and the catchment topography is relatively flat compared to the Gloucester and Barrington catchments. Mining activity in the south of the catchment may also have some influence on the catchment flood hydrology.

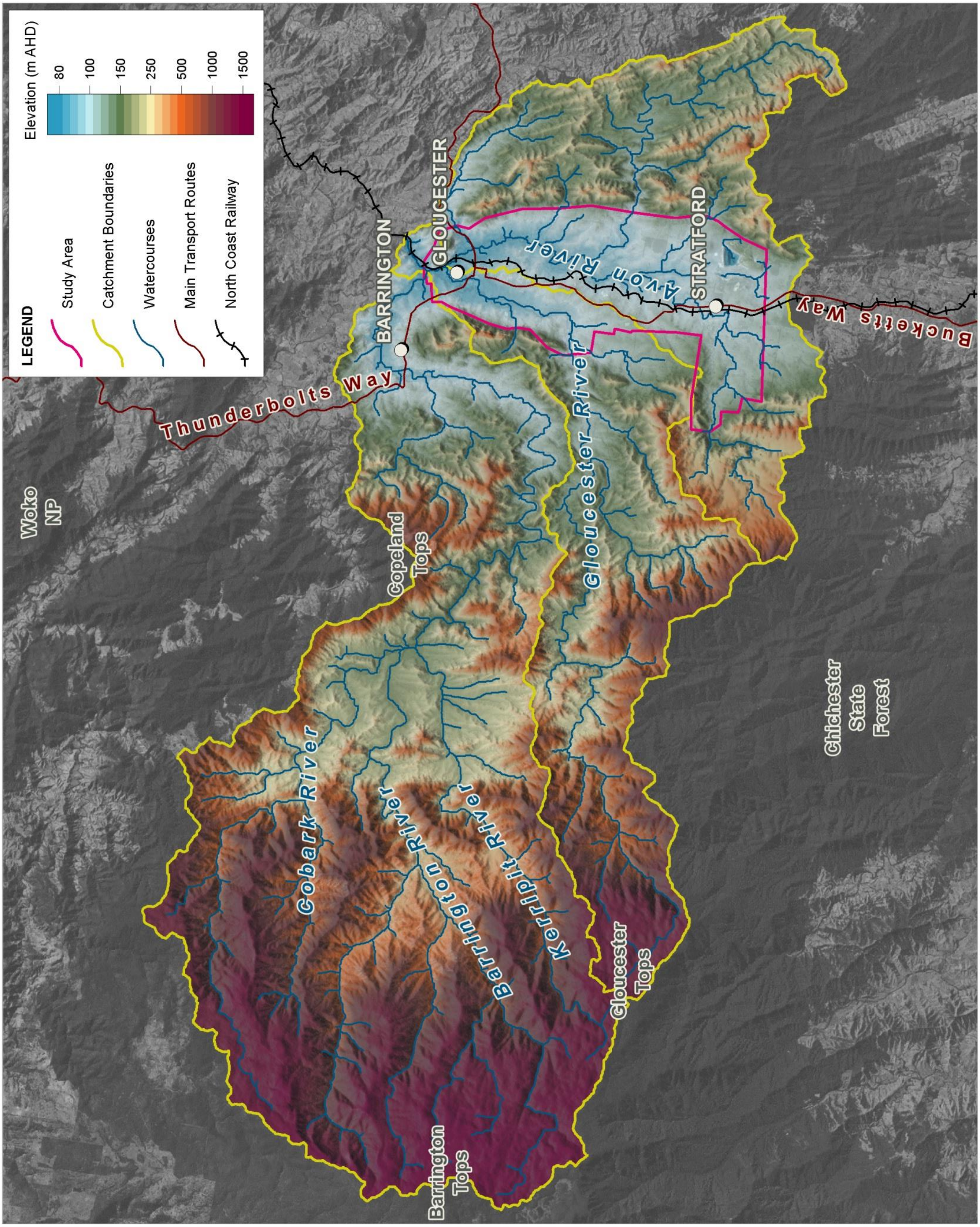
The Gloucester River catchment is some 250km^2 in size upstream of Gloucester and is principally one major watercourse with a long, narrow catchment. The catchment is steeper than that of the Avon River, rising in the Gloucester Tops, which is elevated above 1200m AHD.

The Barrington River catchment is some 700km^2 in size and consists of a number of major tributaries draining the eastern slopes of the Barrington Tops. These form three rivers – the Cobark, Barrington and Kerripit – that join at a single confluence location. This configuration has the potential to generate significant flood flows and subsequent elevated tailwater conditions along the Gloucester River from the Barrington River confluence.

Land use within the catchment primarily consists of forested areas, comprising 70% of the Barrington catchment, 60% of the Gloucester catchment and 65% of the Avon catchment. The remaining land uses are predominantly pastureland and other cultivated areas.

The township of Gloucester is the main community within the catchment, with a population of around 2,500. The much smaller communities of Stratford and Barrington are the other main population centres in the study catchments.

The two main transport routes that traverse the area are the Bucketts Way (connecting Gloucester with Taree 50km to the east and Newcastle 100km to the south) and the Thunderbolts Way (connecting Gloucester with Armidale 170km to the north). The north coast railway also traverses the study area, connecting Maitland to Taree (via Dungog and Gloucester) and the north coast beyond. These transport routes cross the floodplains of the Gloucester, Avon and Barrington Rivers. They may both impact the flood behaviour and/or be impacted by flooding.



Title:
Topography of the Study Catchments

Figure: **2-1**

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BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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The nature of floodplain development within the catchment has and will continue to have an impact on flooding and other natural processes. The condition of riparian vegetation can have a significant impact on the resultant flood conditions within the catchment. Dense riparian vegetation can influence flood hydrology – reducing peak flood flows and slowing the progression of the flood wave. However, it can also locally increase flood levels and increase the potential for arboreal debris to result in structure blockages. This is a complex set of relationships, with insufficient data to incorporate within flood modelling of the catchment. However the influence of riparian vegetation has been considered through both the analysis of available flow gaugings and the modelling of structural blockages and varied channel roughness in the sensitivity analyses.

The more extensive clearing of catchment vegetation, particularly in the Avon River catchment, has caused erosion and sedimentation issues. The clearing of forested vegetation to cleared land results in more frequent catchment runoff, exposing the river channel to larger, more frequent erosional forces. Large channels become carved out of soft bed material in susceptible locations, with the resulting sediment being deposited further downstream. This process is expected to continue to happen and whilst not considered within this study, may be an issue that requires further investigation from a catchment management and landcare perspective. The reinstatement of riparian vegetation or alternative erosion protection measures in the affected locations may help lessen the impact that the clearing of the landscape has had on the Avon River.

2.1.2 History of Flooding

Significant flooding has occurred in the catchment since records began some 150 years ago. The February 1929 flood is the largest on record, reaching a likely level of around 93m AHD on the Gloucester River at Gloucester. Since official gauged records began in 1952 there have been a number of significant flood events. Three large events occurred in the 1950s, the largest of which was in 1956, measuring 91.85m AHD at the Gloucester gauge. The 1970s also saw a number of large flood events, peaking at 90.52m AHD in 1978. After a relatively flood-free period throughout the 1980s and 1990s the 21st century has seen a number of notable flood events, the most significant of which occurred in 2011 and measured 90.39m AHD at the Gloucester gauge.

The text in the following Sections (2.1.2.1 and 2.1.2.2) has been extracted from the Gloucester Flood Study Supplementary Report (Paterson Consultants, 2004), with flood photographs provided by Council.

2.1.2.1 Flooding in the Nineteenth Century

There is some anecdotal evidence of major flooding dating back to 1857. Files from the Gloucester Historical Society reproduced in Willing and Partners, 2001 detail a number of large events which occurred during the 19th century. Seemingly large events occurred in 1857, 1867, 1875, 1878, and 1893, with two smaller events reported in 1871 and 1872.

The 1875 event was apparently the largest of these events as "the whole of the Gloucester flats were covered...(and) the whole of what is Church Street today was two to three feet under water." During the following flood in 1878, two men were swept to their death while attempting to cross The Billabong.

The 1893 flood was the last major flood during the 19th Century. Observations recorded in the Gloucester Advocate of the 1929 flood mention a post in the ground to indicating Gloucester's highest flood level some 35 years prior to the 1929 flood. Both the street and pavement had apparently been built up in the intervening years, yet the 1929 flood exceeded this mark by 6 inches.

2.1.2.2 Flooding in the Twentieth Century

The highest known flood in the area occurred on the 9th February, 1929. During this flood, water inundated shops and businesses in Church Street to approximately four feet in depth. The Royal Hotel and other businesses in Park Street were inundated to a much greater depth and suffered significant damage. The lives of two men were lost while they were attempting to cross between the Royal Hotel and Park Street in order to rescue some of the Hotel guests stranded on the top floor. The newspaper reports clearly indicate the short response time for the Gloucester River to rainfall, and relatively fast rates of floodwater rise. Photographs taken during the flood event are presented in Figure 2-2 to Figure 2-4.

The 1956 flood is the highest since records commenced in 1952. Floodwaters entered many of the shops in Church Street. Photographs taken during the event are presented in Figure 2-5 to Figure 2-7.

The flood of March 1978 is seen as having caused the greatest damage in the area. General local opinion places this flood on the Barrington, Little Manning, Cobark and Dilgry Rivers as higher than the 1929 flood. Several bridges were washed away or severely damaged. In the township of Gloucester, many businesses were again inundated with significant associated damage and loss of stock.

Figure 2-2 Royal Hotel during the 1929 Flood Looking South Along Church Street

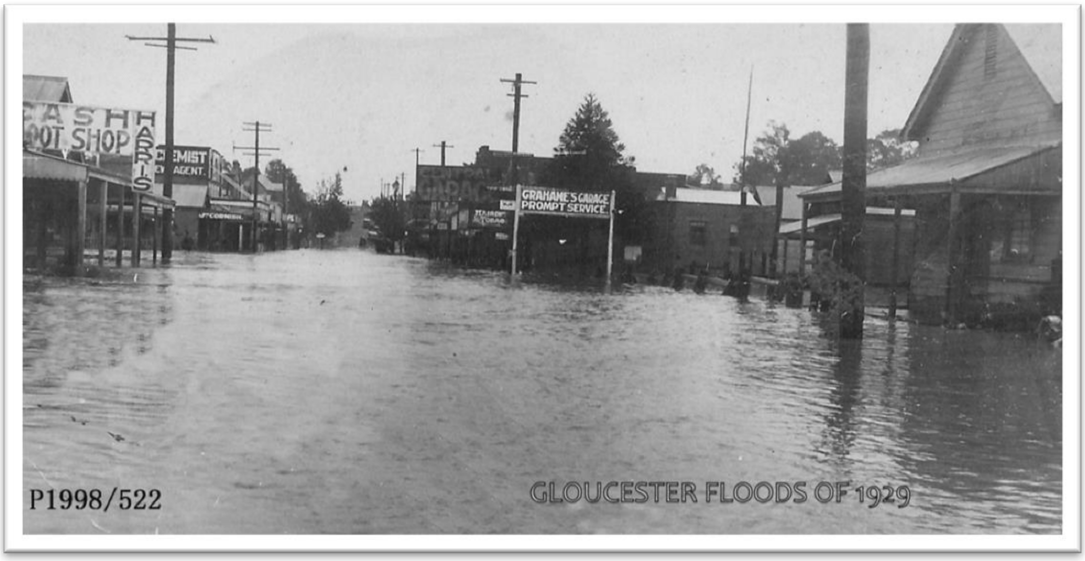


Figure 2-3 Town Centre during the 1929 Flood Looking East

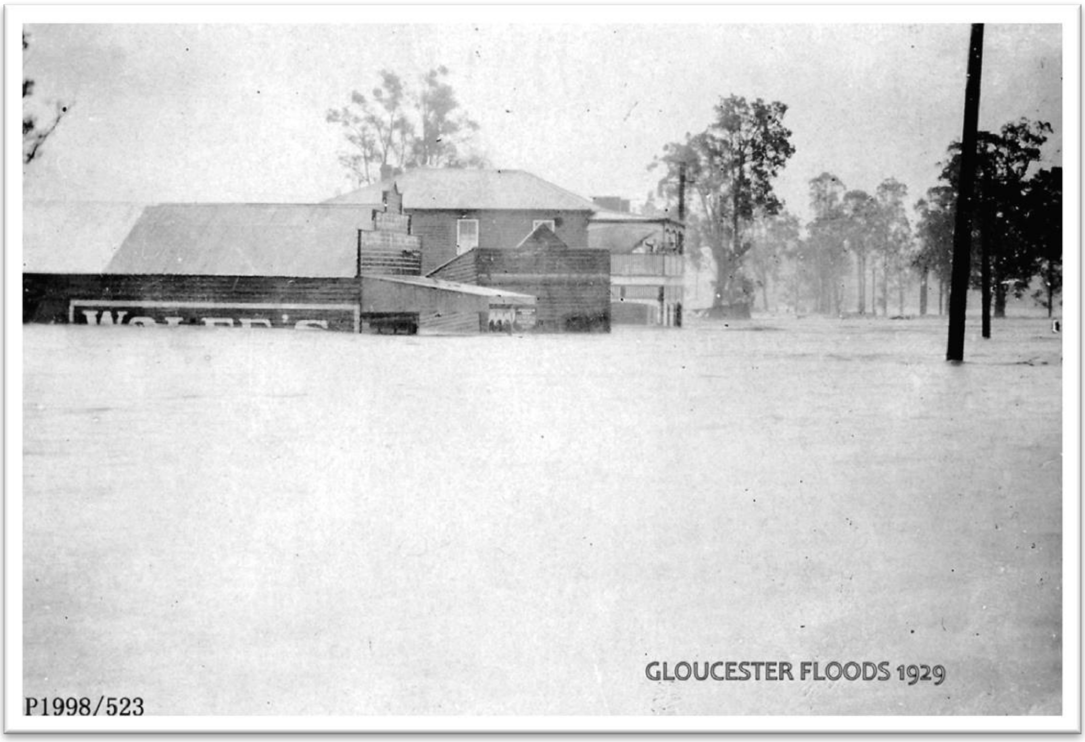


Figure 2-4 Royal Hotel during the 1929 Flood Looking North Along Church Street

Figure 2-5 Grahame’s Garage during the 1956 Flood Looking NW along Park Street

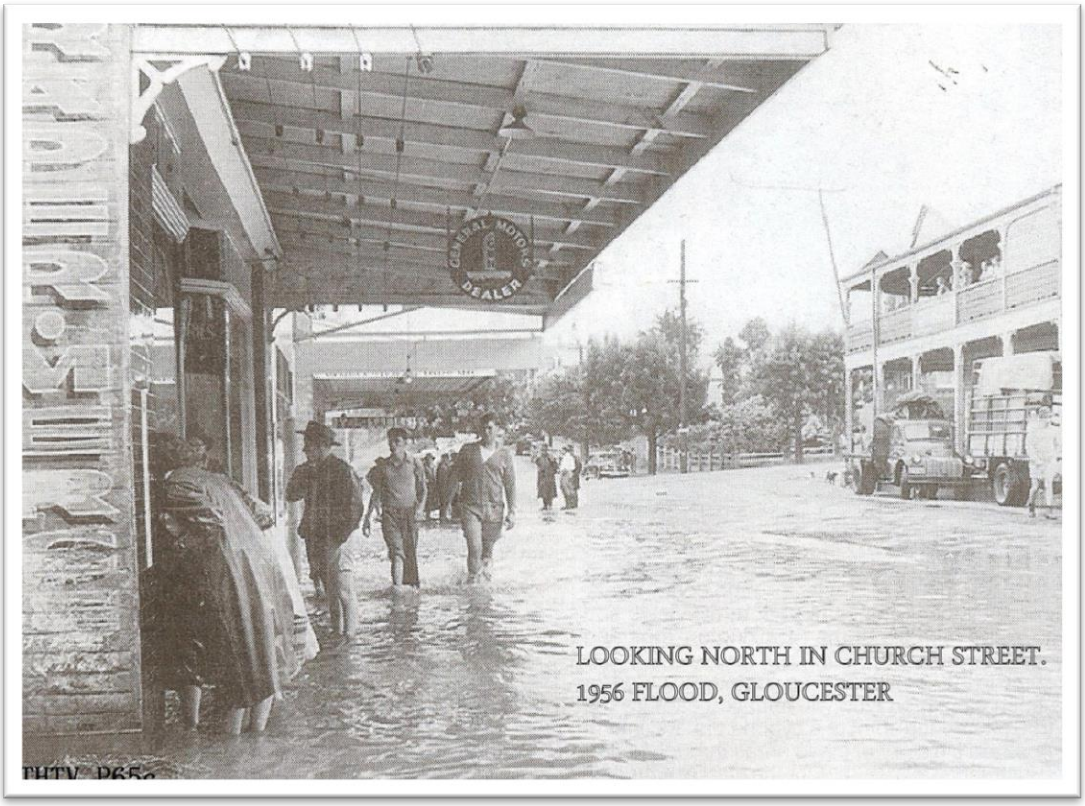


Figure 2-6 Church Street during the 1956 Flood Looking North

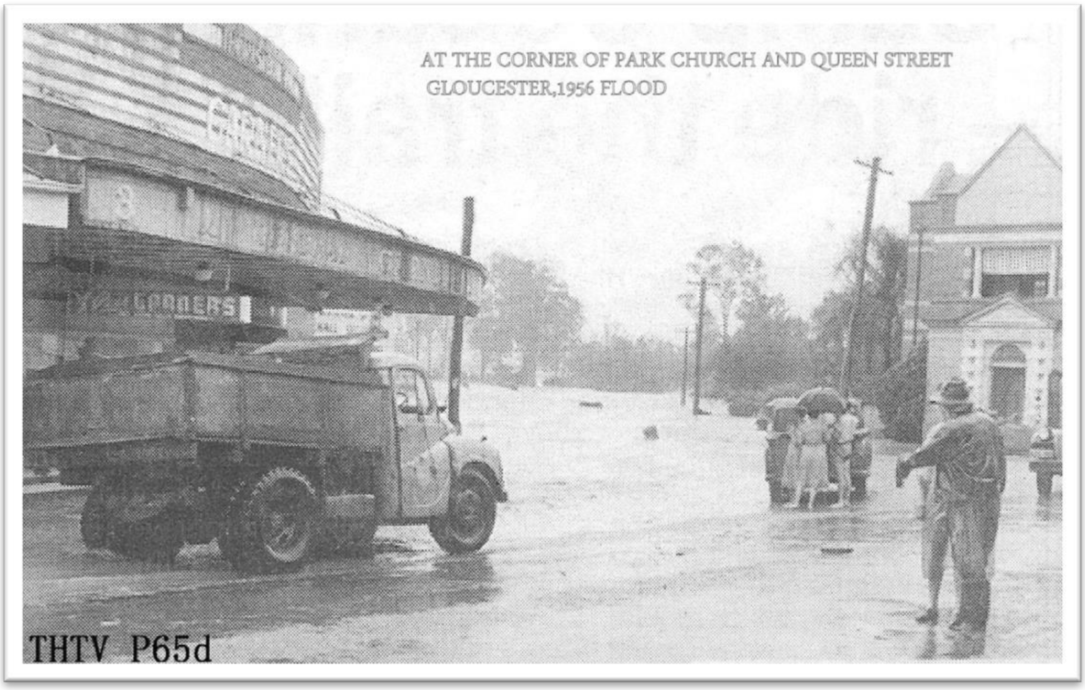


Figure 2-7 Garner's Store during the 1956 Flood Looking NW along Park Street

The scale of the March 1978 flood on the Barrington is evident in the photographs presented in Figure 2-8 to Figure 2-10, particularly the magnitude of flows over the Thunderbolts Way at Barrington and the subsequent damage to the road. The flooding within Gloucester was restricted to properties adjacent to Billabong Lane and did not result in flood flows along Church Street, as had occurred in 1929 and 1956. Photographs taken in Gloucester during the event are presented in Figure 2-11 to Figure 2-13.

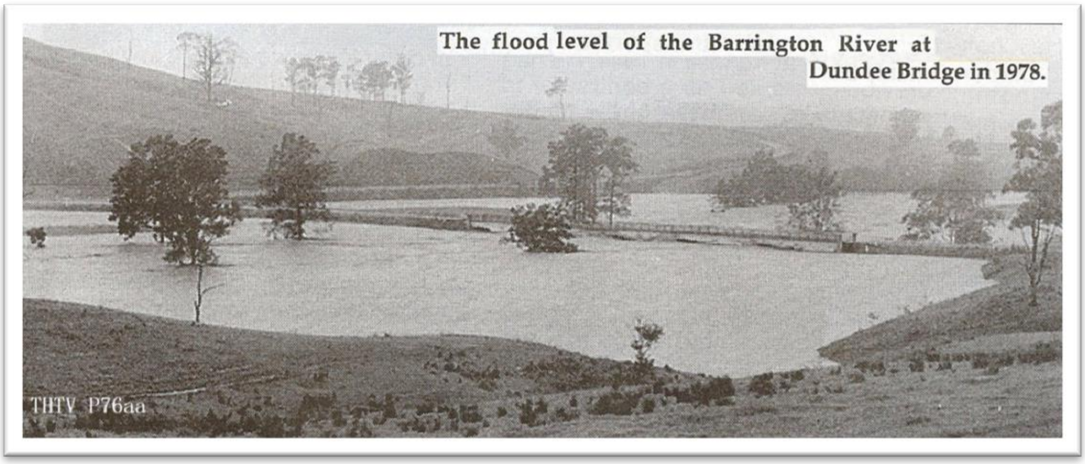


Figure 2-8 Dundee Bridge (Bowman Farm Rd) during the 1978 Flood

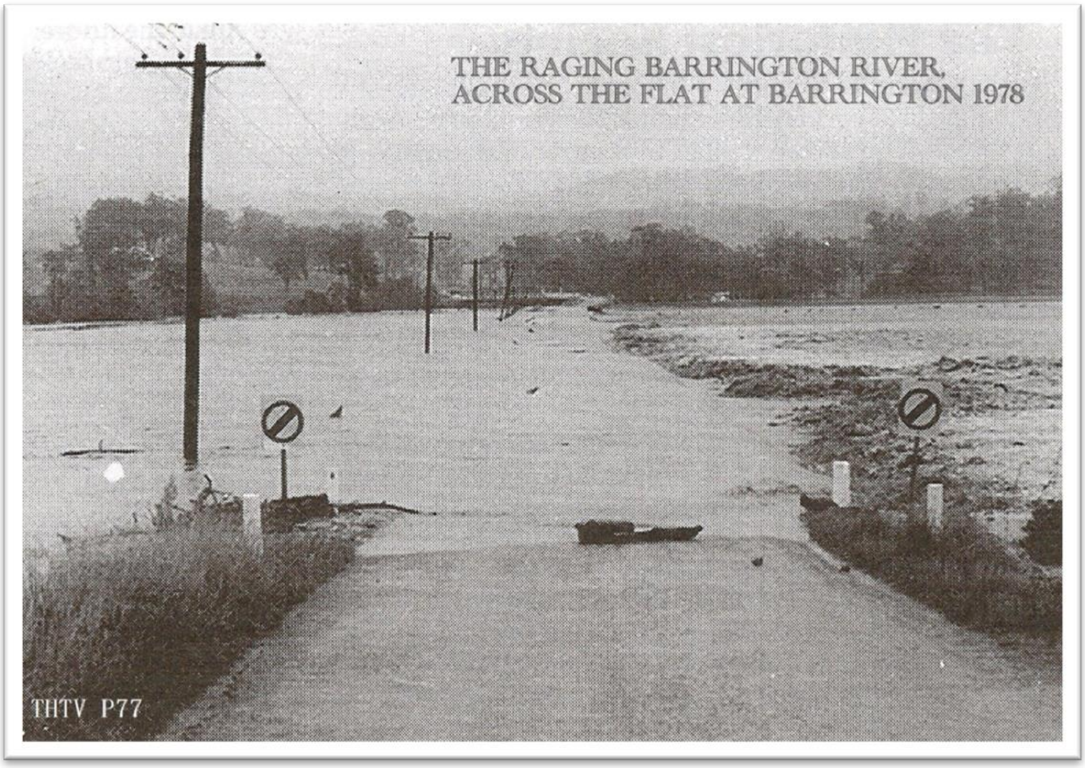


Figure 2-9 Thunderbolts Way at Barrington during the 1978 Flood

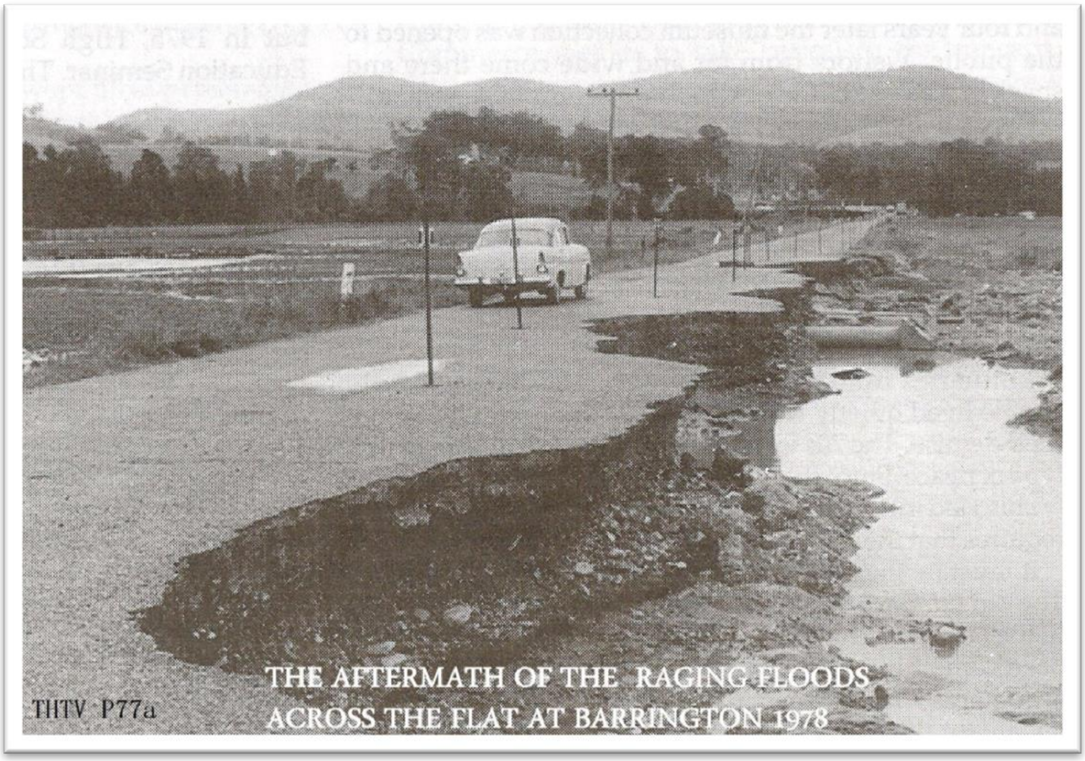


Figure 2-10 Thunderbolts Way at Barrington following the 1978 Flood

Figure 2-11 Denison Street during the 1978 Flood

Figure 2-12 Billabong Lane at the Rear of the Bakery during the 1978 Flood

Figure 2-13 Holden Garage during the 1978 Flood Looking NW along Park Street

Other major flood events to have occurred since the installation of the Gloucester (Lehmans Flat Bridge) gauge and commencement of official records include floods in 1957, 1963 (twice), 1974, and 1976.

The 1963 flood presents an anomaly in that the 1963 flood was smaller than the 1978 flood at Lehmans Flat, but entered the Olympic Swimming Pool, which the 1978 flood did not. However, it is likely that local changes in topography resulted in this apparent discrepancy.

More recent flooding occurred in 2011 and 2013, the former of which resulted in minor flooding along Billabong Lane, as presented in Figure 2-14 and Figure 2-15.

Less is known about flooding in the Avon River catchment. For the 1978 event it is understood that there was no major flooding from the upper Avon and that the majority of flood flow contributions were from runoff from the eastern tributaries, such as Waukivory Creek. A flood event in 1991 was the largest in recent times on the upper Avon. This caused overtopping of the Bucketts Way at the low point in the road near the Stratford mine.

2.2 Compilation and Review of Available Data

2.2.1 Previous Studies

A flood study for Gloucester was undertaken by Willing and Partners in 1999, with a draft report issued in 2000. Following review of this study further investigations were commissioned. In 2004 Paterson Consultants produced the Gloucester Floodplain Management Study. This was supported by a Supplementary Flood Study Report.

Figure 2-14 The Billabong at Denison Street during the 2011 Flood

Figure 2-15 The Billabong at Denison Street following the 2011 Flood

The 2004 study was based on a MIKE11 model that covered the Gloucester River downstream from the Forbesdale gauge, the lower 6km of the Avon River and the lower 3km of the Barrington River.

2.2.1.1 *Gloucester Flood Study (Willing and Partners, 2000)*

In 1999-2000 Willing and Partners undertook a flood study of Gloucester. The study included the development of an EXTRAN hydraulic model and calibration to the 1978, 1976 and 1929 flood events. The study progressed to Draft Report stage, but during review it was found that there were discrepancies between the historical floods and the modelled design floods. The study was not adopted and instead the Floodplain Management Committee commissioned Paterson Consultants to undertake additional investigations in order to resolve these discrepancies.

2.2.1.2 *Gloucester Flood Study Supplementary Report (Paterson Consultants, 2004)*

In 2004 Paterson Consultants completed the Gloucester Flood Study Supplementary Report, which built upon the previous study undertaken by Willing and Partners. The investigations undertaken for the Supplementary Report included a more comprehensive compilation and analysis of the available historic flood information. A MIKE 11 hydraulic model was developed from the original EXTRAN model and a number of improvements were made. These included extension of the model at the upstream and downstream limits, correction of survey datum errors and an improved representation of The Billabong. The model was calibrated using the 1978, 1976 and 1929 flood events, although known information about other historic events was also presented.

The 2000 study had placed the 1929 flood event at around a 0.05% AEP design equivalent, which was one of the reasons for initiating the additional investigations. Flood frequency analyses undertaken for flood level records at the Lehmans Flat Bridge gauge and the intersection of Church Street and Denison Street estimated the 1929 flood to be in the order of a 1% AEP design magnitude. Design flood conditions were modelled for the 20%, 10%, 5%, 2% and 1% AEP events and the Probable Maximum Flood (PMF). Model results were presented for flood levels, discharges and average velocities. Flood hazard and hydraulic categorisation was also determined. These results provided the basis for the Floodplain Risk Management Study. Information relating to historic flood events, including recorded flood levels has been taken from the Supplementary Report for use in this study.

2.2.1.3 *Gloucester Floodplain Management Study (Paterson Consultants, 2004)*

The Gloucester Floodplain Management Study was undertaken by Paterson Consultants in conjunction with the Flood Study Supplementary Report. The Management Study utilised results from the Flood Study modelling to describe and quantify flood risk within Gloucester. Future management actions to reduce flood risk were recommended.

A flood damages assessment formed the basis for quantification of the economic impact of flooding in Gloucester and a baseline from which to assess potential measures to reduce the damages sustained during flood events. The damages assessment utilised a properties database containing surveyed floor levels and the modelled design peak flood levels.

Flood planning controls were also defined, based on the design peak flood level surfaces plus freeboard allowances. This formed one of the main recommendations of the Management Plan. The other key recommendations were the development of a Flood Plan for the caravan park and the operation of a flood warning system. The previous flood warning system had relied on the manual reading of gauge boards, which was often not possible during flood events. The water level gauges have since been added to the telemetry network, enabling more effective flood warning in the catchment.

2.2.2 Water Level Data

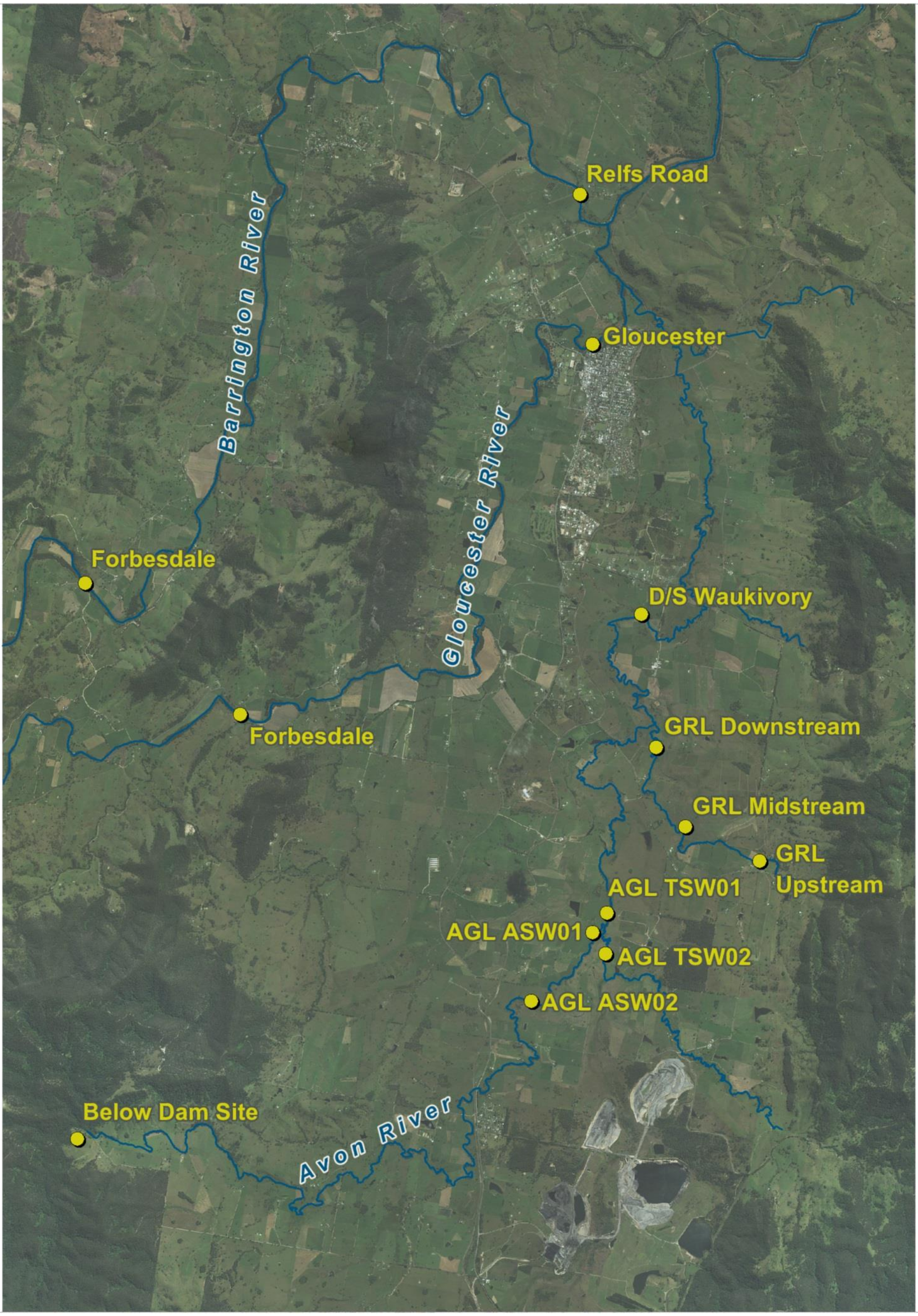
There are a number of locations within the catchment at which water levels have been recorded either continuously or intermittently. The continuous water level gauging locations are presented in Figure 2-16 and summarised in Table 2-1. Additional locations at which flood peaks have been gauged are discussed in Section 6.

Table 2-1 Study Catchment Continuous Water Level Gauge Summary

Gauge #	Location	Period of Record	Catchment Area (km^2)
208006	Forbesdale (Barrington)	1945 – current	590
208031	Relfs Road (Barrington)	2010 – current	700
208008	Forbesdale (Gloucester)	1948 – current*	200
208020	Gloucester (Gloucester)	2003 – current	250
208018	Below Dam Site (Avon)	1971 – 1985	32
208028	D/S Waukivory (Avon)	2004 – current	225
AGL	ASW02 (Avon)	2011 – current	76
AGL	ASW01 (Avon)	2011 – current	78
AGL	TSW01 (Avon)	2011 – current	120
AGL	TSW02 (Dog Trap)	2012 – current	39
GRL	Upstream Site (Waukivory)		79
GRL	Midstream Site (Waukivory)		83
GRL	Downstream Site (Waukivory)		85

**The Gloucester River Gauge at Forbesdale was decommissioned between 1985 and 2004*

The gauges with the longest period of record and the most important for catchment flood frequency analysis are the Forbesdale gauges on the Barrington and Gloucester Rivers. The Relfs Road, Gloucester and D/S Waukivory are newer gauges located on the Barrington, Gloucester and Avon Rivers respectively. Although continuous records only began at the Gloucester gauge in 2003 the SES have gauged peak flood levels there since 1952. The Below Dam Site gauge on the Avon River is an older gauge that ceased recording in 1985. In addition to these NSW Office of Water gauges there are a number of privately operated gauges in the Avon River catchment. These include four gauges operated by AGL and another three by GRL.



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Water Level Gauges of the Study Catchment

Figure: 2-16

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To provide an indicative flood record for Gloucester, Table 2-2 presents the ten highest gauge readings from the Gloucester (Lehmans Flat Bridge) gauge on the Gloucester River. Since gauge readings began in 1952 most of the largest floods have been in the 1950s, 60s and 70s, the largest of which was in March 1956. More recently, significant floods have occurred in 2005 and 2011.

Similar gauged flood summaries are presented in Table 2-3 and Table 2-4 at Forbesdale on the Gloucester and Barrington Rivers respectively. Comparison of the flood events listed in Table 2-2 with those listed in Table 2-3 and Table 2-4 provides a useful insight into the flood behaviour at Gloucester. Of the ten largest floods in Gloucester since 1952, six of them correspond to the ten largest floods gauged over a similar period on the Gloucester River at Forbesdale, some 13km upstream. Of the four that are not listed, the March 1963 and February 1954 floods feature within the ten largest floods on the Barrington River. However, the February 1957 and January 1974 floods (which are two of the largest four at Gloucester) do not feature in the ten largest on the Gloucester River or Barrington River. It is possible that significant floods on the Avon River contributed to the high flood conditions in Gloucester for these events.

Table 2-2 Gloucester Peak Gauge Levels

Rank	Flood Event	Gauge Height (m)	Flood Level (m AHD)
1	March 1956	6.71	91.85
2	February 1957	6.10	91.24
3	March 1978	5.38	90.52
4	June 2011	5.54*	90.39
5	January 1974	5.20	90.34
6	March 1976	5.18	90.32
7	May 1963	5.11	90.25
8	March 1963	4.95	90.09
9	June 2005	5.11*	89.96
10	February 2013	4.75*	89.60

**When the continuous gauge was established in 2003 the gauge zero was changed from 85.14m AHD to 84.85m AHD*

Table 2-3 Forbesdale (Gloucester River) Peak Gauge Levels

Rank	Flood Event	Gauge Height (m)	Flood Level (m AHD)
1	March 1956	3.53	128.17
2	March 1978	3.14	127.78
3	February 1955	3.07	127.71
4	June 2011	2.87	127.51
5	March 1976	2.78	127.42
6	June 2005	2.64	127.28
7	February 2013	2.60	127.24
8	June 1950	2.59	127.23
9	May 1963	2.59	127.23
10	March 1957	2.59	127.23

Table 2-4 Forbesdale (Barrington River) Peak Gauge Levels

Rank	Flood Event	Gauge Height (m)	Flood Level (m AHD)
1	March 1978	6.87	131.40
2	February 1956	5.82	130.35
3	February 1990	5.30	129.83
4	June 2011	5.00	129.53
5	March 1963	4.88	129.41
6	February 2013	4.86	129.39
7	February 1954	4.65	129.18
8	February 1955	4.57	129.10
9	March 1956	4.54	129.07
10	January 1976	4.53	129.06

Continuous gauge records were obtained where available for the selected calibration events, discussed in Section 6. The Gloucester and Forbesdale gauges are discussed further in Section 7.3, which provides flood frequency analyses at the sites.

2.2.3 Historical Flood Levels

In addition to the gauge sites discussed in Section 2.2.2 there are a number of other locations around Gloucester at which historic flood levels have been recorded. This information was compiled and presented in the Gloucester Flood Study Supplementary Report. From the available information a composite table of flood level estimates at the intersection of Church Street and Denison Street was made, as presented in Table 2-5. The June 2011 flood level has been estimated from the available information and included for reference. It can be seen that the relative magnitude of the estimated flood levels in Table 2-5 correspond well to those at the Gloucester gauge presented in Table 2-2.

Table 2-5 Estimated Peak Flood Levels in Gloucester Town

Rank	Flood Event	Flood Level (m AHD)
1	February 1929	93.5
2	1894	93.3
3	March 1956	92.9
4	February 1957	92.6
5	March 1978	92.5
6	March 1976	92.4
7	May 1963	92.3
8	June 2011	91.7

2.2.4 Rainfall Data

There are relatively few rainfall gauges located within the study catchments, particularly in the mountainous areas of the west. However, there is a more extensive network of gauges across the broader region which can be used to assist the study. The continuous gauge locations identified within 20km of the study catchments are shown in Table 2-6 with the daily gauges shown in Table 2-7. The distribution of these gauges is shown in Figure 2-17.

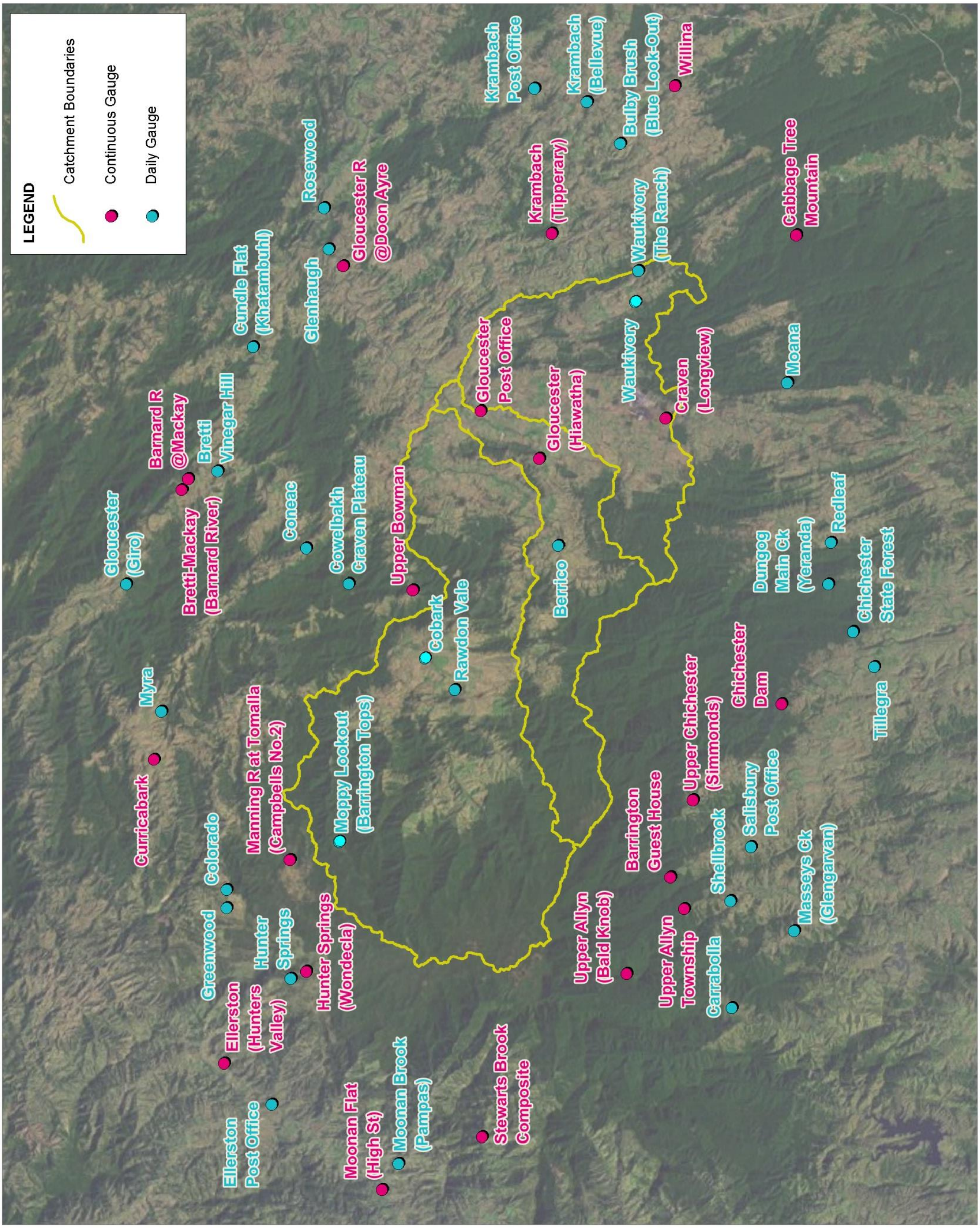
Table 2-6 Continuous Rainfall Gauges in the Vicinity of the Study Catchments

Station #	Name	Source	Start Year	End Year
60015	Gloucester Post Office	BoM Operational	1995	current
60042	Craven (Longview)	BoM Operational	1992	current
60075	Upper Bowman	BoM Operational	1989	current
60096	Cabbage Tree Mountain	BoM Operational	2002	current
60103	Krambach (Tipperary)	BoM Operational	2002	current
60112	Gloucester (Hiawatha)	BoM Continuous	1982	current
60137	Bretti-Mackay (Barnard River)	BoM Operational	1999	current
60148	Willina	BoM Operational	2003	current
61097	Moonan Flat (High St)	BoM Continuous	1955	1961
61136	Barrington Guest House	BoM Operational	2000	current
61151	Chichester Dam	BoM Continuous	1960	current
61246	Ellerston (Hunters Valley)	BoM Continuous	1966	1994
61290	Upper Allyn Township	BoM Operational	1999	current
61325	Upper Allyn (Bald Knob)	BoM Continuous	1972	1995
61335	Stewarts Brook Composite	BoM Continuous	1969	1982
61346	Hunter Springs (Wondecla)	BoM Continuous	1976	1991
61346	Hunter Springs (Wondecla)	BoM Operational	1990	current
61350	Upper Chichester (Simmonds)	BoM Operational	1999	current
208002	Manning R at Tomalla (Campbells No.2)	NSW Office of Water	1958	1981
208003	Gloucester R @Doon Ayre	NSW Office of Water	1991	current
208011	Barnard R @Mackay	NSW Office of Water	1993	current
560028	Curricabark	BoM Operational	1998	current

There are a large number of gauges recording continuous rainfall in the vicinity of the catchment, including three located within the catchment. However, most of these have only been installed within the last 25 years and many have only been operational for around 15 years. This provides a substantial dataset for the more recent flood events but a limited coverage of data for other events.

There are further 20 daily rainfall gauges within the vicinity of the study catchment that can provide valuable information on the spatial variability of rainfall during significant rainfall events. The period of record for these gauges is much more extensive, with most gauges being at least 50 years old and many of which are still operational.

Further discussion on recorded rainfall data for historical events is presented with the calibration and validation of the models developed for the study in Section 6.



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Rain Gauges in the Vicinity of the Study Catchments

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Table 2-7 Daily Rainfall Gauges in the Vicinity of the Study Catchments

Station #	Name	Source	Start Year	End Year
60003	Bulby Brush (Blue Look-Out)	BoM Daily	1925	current
60007	Cowelbakh Craven Plateau	BoM Daily	1937	1961
60015	Gloucester Post Office	BoM Daily	1888	current
60016	Greenwood	BoM Daily	1908	1948
60021	Krambach Post Office	BoM Daily	1910	current
60033	Krambach (Bellevue)	BoM Daily	1908	current
60037	Glenhaugh	BoM Daily	1945	1996
60043	Colorado	BoM Daily	1961	1971
60045	Berrico	BoM Daily	1962	1978
60049	Coneac	BoM Daily	1961	1970
60053	Bretti - Vinegar Hill	BoM Daily	1961	current
60057	Myra	BoM Daily	1961	1971
60059	Rawdon Vale	BoM Daily	1961	1970
60062	Waukivory (The Ranch)	BoM Daily	1961	current
60075	Upper Bowman	BoM Daily	1965	current
60081	Gloucester (Giro)	BoM Daily	1966	2006
60089	Moana	BoM Daily	1968	1979
60102	Cundle Flat (Khatambuhl)	BoM Daily	1970	current
60103	Krambach (Tipperary)	BoM Daily	1970	current
60107	Rosewood	BoM Daily	1971	1986
60112	Gloucester (Hiawatha)	BoM Daily	1976	current
60152	Cobark	BoM Daily	2008	current
60153	Moppy Lookout (Barrington Tops)	BoM Daily	2008	current
60155	Waukivory	BoM Daily	2008	current
61045	Redleaf	BoM Daily	1914	1970
61068	Salisbury Post Office	BoM Daily	1938	1981
61097	Moonan Flat (High St)	BoM Daily	1897	current
61122	Tillegra	BoM Daily	1960	1986
61136	Barrington Guest House	BoM Daily	1960	current
61145	Carrabolla	BoM Daily	1960	1964
61151	Chichester Dam	BoM Daily	1942	current
61155	Ellerston 2 Post Office	BoM Daily	1960	1972
61163	Hunter Springs	BoM Daily	1960	1970
61170	Dungog - Main Ck (Yeranda)	BoM Daily	1960	current
61189	Shellbrook	BoM Daily	1960	1981

Station #	Name	Source	Start Year	End Year
61246	Ellerston (Hunters Valley)	BoM Daily	1966	1994
61292	Masseys Ck (Glengarvan)	BoM Daily	1969	current
61302	Chichester State Forest	BoM Daily	1938	1958
61335	Stewarts Brook Composite	BoM Daily	1891	1983
61346	Hunter Springs (Wondecla)	BoM Daily	1971	current
61350	Upper Chichester (Simmonds)	BoM Daily	1981	current
61399	Moonan Brook (Pampas)	BoM Daily	2003	current

2.2.5 Council Data

A number of spatial datasets were provided by Council for use in the study. These included Light Detection and Ranging (LiDAR), topographic survey and aerial photography.

LiDAR survey data was sourced from two datasets – one through AGL covering some 220km^2 and another through Midcoast Water covering some 350km^2. The former was surveyed in September 2013 and the latter in January 2012. Aerial photography at a 10cm resolution also accompanied the Midcoast Water dataset. Modelled flood behaviour is inherently dependent on the ground topography and for this study an accurate representation of the floodplain is essential. Advanced GIS analysis allows the LiDAR imagery to be assessed in concert with spatial 2-D flood model data, facilitating mapping and flood risk categorisation, and overall flood management.

Topographic survey of river cross sections for parts of the Gloucester and Barrington Rivers was provided, along with floor level survey of the previously identified flood affected properties.

Existing flood information was made available, including historic flood photographs of the 1929, 1956 and 1978 events and the more recent event in June 2011.

2.3 Site Inspections

A number of site inspections were undertaken during the course of the study to gain an appreciation of local features influencing flooding behaviour. Some of the key observations to be accounted for during the site inspections included:

- Presence of local structural hydraulic controls including the road and rail bridges and associated embankments;
- General nature of the Gloucester, Avon and Barrington Rivers, their tributary channels and associated floodplains noting river plan form, vegetation type and coverage and the presence of significant flow paths;
- Location and configuration of key gauging stations to assist in extending the rating curves to provide accurate model calibration and flood frequency analyses; and
- Location of existing development and infrastructure on the floodplain..

This visual assessment was useful for defining hydraulic properties within the hydraulic model and ground-truthing of topographic features identified from the survey datasets.

2.4 Survey Requirements

A number of datasets containing topographic information were available from Council and are summarised as follows:

- LiDAR survey data sourced through AGL from September 2013;
- LiDAR survey data sourced through Midcoast Water from January 2012;
- Topographic ground survey of Gloucester River and Barrington River cross sections; and
- Channel bed elevations along the Avon River as documented in the Gloucester Gas Project Hydrology Study.

Further information on the extent of the available survey is presented in Section 5.2.4 which details the use of the survey in the model development.

Extensive analysis was undertaken to assess the adequacy of the available survey datasets for flood modelling purposes. This analysis, which confirmed that no additional survey acquisition was required, is detailed in Section 4.

2.5 Community Consultation

The success of a Floodplain Management Plan hinges on its acceptance by the community and other stake-holders. This can be achieved by involving the local community at all stages of the decision-making process. This includes the collection of their ideas and knowledge on flood behaviour in the study area, together with discussing the issues and outcomes of the study with them.

The key elements of the consultation process in undertaking the flood study have included:

- Issue of a questionnaire to obtain historical flood data and community perspective on flooding issues; and
- Public exhibition of Draft Report and community information session.

These elements are discussed in further detail in Section 3.

2.6 Development of Computer Models

2.6.1 Hydrological Model

For the purpose of the Flood Study, a hydrologic model (discussed in Section 5.1) was developed to simulate the rate of storm runoff from the catchment. The model predicts the amount of runoff from rainfall and the attenuation of the flood wave as it travels down the catchment. This process is dependent on:

- Catchment area, slope and vegetation;
- Variation in distribution, intensity and amount of rainfall; and
- Antecedent conditions of the catchment.

The output from the hydrologic model is a series of flow hydrographs at selected locations such as at the boundaries of the hydrodynamic model. These hydrographs are used by a hydrodynamic model to simulate the passage of a flood through the study catchments to the downstream study limits beyond the confluence of the Gloucester and Barrington Rivers.

2.6.2 Hydraulic Model

The hydraulic model (discussed in Section 5.2) developed for this study includes:

- Two-dimensional (2D) representation of the channel and floodplain of the Gloucester, Avon and Barrington Rivers and other major watercourses, covering an area of some 220 km^2 of the catchment (approximately 18% of total catchment area); and
- One-dimensional (1D) representation of key hydraulic structures within Gloucester township and the surrounding floodplain.

The hydraulic model is applied to determine flood levels, velocities and depths across the study area for historical and design events.

2.7 Calibration and Sensitivity Testing of Models

The hydrologic and hydraulic models were calibrated and verified to available historical flood event data to establish the values of key model parameters and confirm that the models were capable of adequately simulating real flood events.

The following criteria are generally used to determine the suitability of historical events to use for calibration or validation:

- The availability, completeness and quality of rainfall and flood level event data;
- The amount of reliable data collected during the historical flood information survey; and
- The variability of events – preferably events would cover a range of flood sizes.

The major historical flood events of February 1929, March 1956, March 1978, June 2011 and February 2012 were identified as suitable events for calibration/validation of the developed models. Assessment of the model performance also incorporated a range of sensitivity tests of key variables/model assumptions. Sensitivity testing was undertaken for the design flood events and has been reported in Section 6.

2.8 Establishing Design Flood Conditions

Design floods are statistical-based events which have a particular probability of occurrence. For example, the 1% Annual Exceedance Probability (AEP) event is the best estimate of a flood with a peak discharge that has a 1% (i.e. 1 in 100) chance of occurring in any one year. For the study catchments, design floods were based on a combination of flood frequency and design rainfall estimates in accordance with the procedures Australian Rainfall and Runoff (IEAust, 2001). In accordance with Council’s brief, the design events to be simulated include the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF event.

The design flood conditions form the basis for floodplain management in the catchment and in particular design planning levels for future development controls. The adopted design flood conditions are presented in Section 7.

2.9 Mapping of Flood Behaviour

Design flood mapping is undertaken using output from the hydraulic model. Maps are produced showing water level, water depth and velocity for each of the design events. The maps present the peak value of each parameter. Provisional flood hazard categories and hydraulic categories are derived from the hydrodynamic model results and are also mapped. The mapping outputs are described in Section 8 and presented in the accompanying flood mapping compendium.

3 Community Consultation

3.1 The Community Consultation Process

Community consultation has been an important component of the current study. The consultation has aimed to inform the community about the development of the flood study and its likely outcome as a precursor to subsequent floodplain management activities. It has provided an opportunity to collect information on their flood experience and their concerns on flooding issues.

The key elements of the consultation process have been as follows:

- Production of a community information brochure providing information on the study;
- Distribution of a questionnaire to landowners, residents and businesses within the study area;
- An information session for the community to present information on the progress and objectives of the flood study and obtain feedback on historical events in the catchment and other flooding issues; and
- Public exhibition of the draft Flood Study.

These elements are discussed in detail below. The community information brochure and questionnaire are also provided in Appendix A

3.2 Community Information Brochure

A community information brochure was produced providing background to the current study, why flood studies are undertaken and how the community can get involved. It was mailed to residents in the study area, along with the community questionnaire in July 2014.

3.3 Community Questionnaire

A community questionnaire was sent out to some 2,400 residents and businesses in Gloucester, Stratford, Barrington and the surrounding areas. The questionnaire sought to collect information on previous flood experience and flooding issues. The focus of the questionnaire was historical flooding information that may be useful for correlating with predicted flooding behaviour from the modelling.

In total 100 questionnaire returns were received, which represents less than a 5% response rate. Around half of the respondents indicated that they had been affected by flooding in the past, with 20% expressing concerns about future flooding. Most of those affected by flooding related to disruption of traffic with only a few whose home or business content had been flooded.

The majority of responses suggested that heavy rains were the principal driver of flooding problems within the catchment, with some also citing blockages of bridges from fallen trees or other debris.

As expected, much reference to flooding concerned the recent events within the past few years. Some respondents provided rainfall data, observations of flood levels and flood photographs. However, these added limited value over and above the existing available datasets.

3.4 Community Information Session

A community information session was held during the public exhibition period on the evening of 20th November at Council. An overview of the study was presented to the attendees, followed by a question and answer session.

3.5 Public Exhibition

The Draft Flood Study Report was placed on public exhibition for a three week period between 10th November and 30th November 2014. The exhibition sought public comments and feedback on the study.

4 Survey DTM Adequacy

A number of datasets containing topographic information were available from Council and are summarised as follows:

- LiDAR survey data sourced through AGL from September 2013;
- LiDAR survey data sourced through Midcoast Water from January 2012;
- Topographic ground survey of Gloucester River and Barrington River cross sections; and
- Channel bed elevations along the Avon River as documented in the Gloucester Gas Project Hydrology Study.

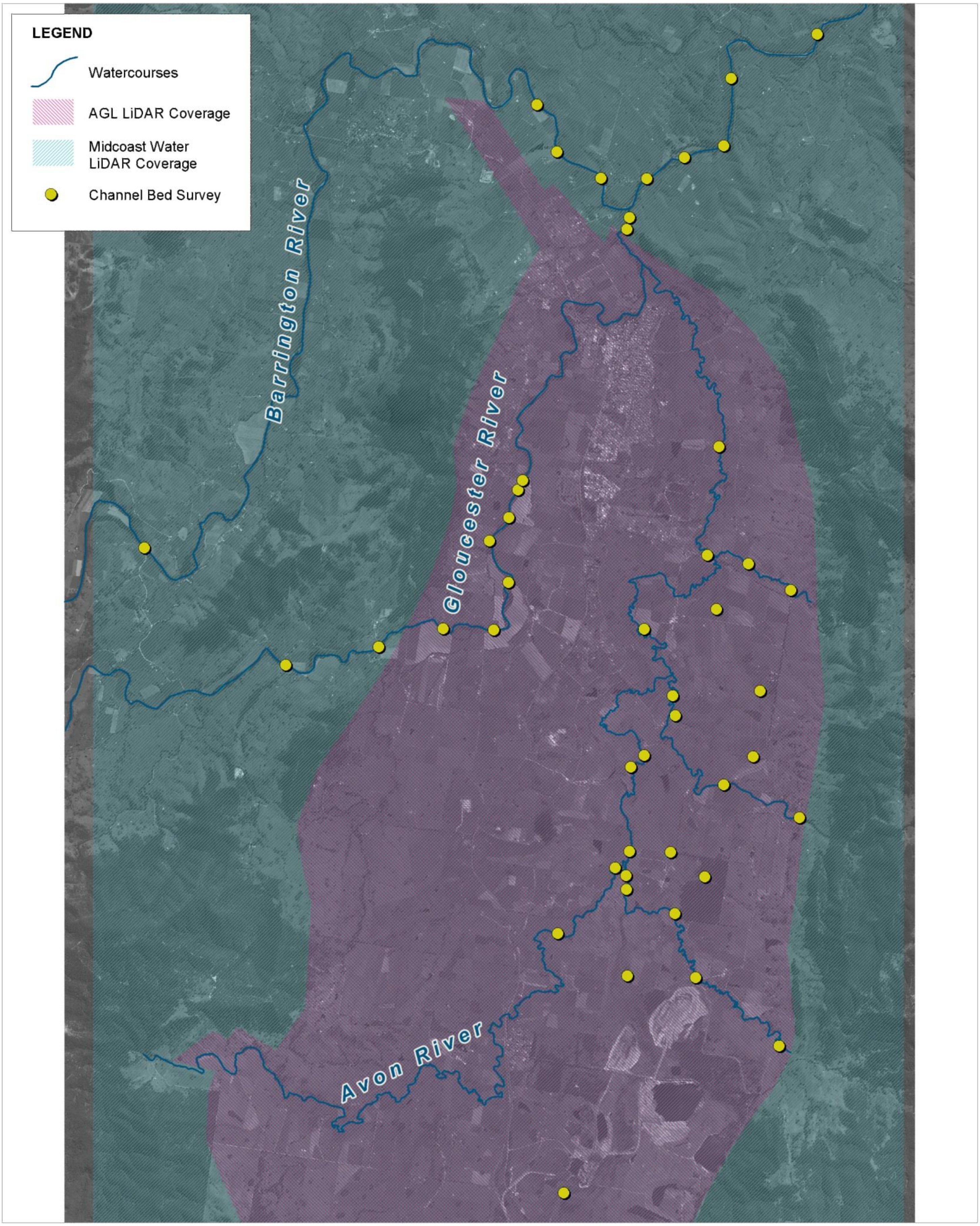
The extent of these survey datasets is presented in Figure 4-1.

One of the initial tasks when undertaking a flood study is to identify the need for any additional survey requirements. This section outlines the analytical process that was undertaken in order to assess the adequacy of the available data. This process determined that the acquisition of additional survey data would not be of significant benefit to the flood study process and that the available datasets provided an adequate representation of floodplain and channel topography.

An accurate centreline of the Gloucester River, Avon River, Barrington River, Oaky Creek, Waukivory Creek and Dog Tap Creek watercourses was digitised utilising both the LiDAR survey DEM and high resolution aerial photography. The lowest LiDAR elevations in the vicinity of the centrelines were extracted to produce long profiles of the channel topography. Available elevation data for the channel bed and water surface from the channel bed survey was also extracted and compared to the LiDAR long profiles. The results of this comparison for the modelled lengths of the Gloucester River, Avon River and Barrington River are presented in Figure 4-2, Figure 4-3 and Figure 4-4 respectively.

The derived channel profile was adopted as being representative of the low-flow channel topography and was used to define the channel elevations in the hydraulic model. Adopting the lowest bed elevations in this situation would likely over-estimate the channel conveyance, as local elevated bed levels act as hydraulic controls and the bed levels of the deep sections behind the controls are not representative of the true channel conveyance (pool and riffle system), particularly in the lower reaches of the Gloucester and Barrington Rivers near Gloucester. This can be observed through the difference between the surveyed bed levels and water surface profile. The river flow at the time of the survey was quite low, but has resulted in relatively large water depths that are typically around 1m.

The heavily vegetated nature of the Avon River is evident in Figure 4-4. The long profile shows that the LiDAR survey in parts has penetrated through the riparian vegetation and has captured a good representation of the low-flow channel topography. The high degree of spatial variation in the LiDAR elevations representing the bed profile due to vegetation influences is evident. This variability has been treated by deriving the 10th percentile of elevations within a moving 200m length of long profile chainage, the result of which has also been presented. It can be seen that the LiDAR derived long profile elevation is consistently between the surveyed bed level and water surface.



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Extent of Available Survey Data

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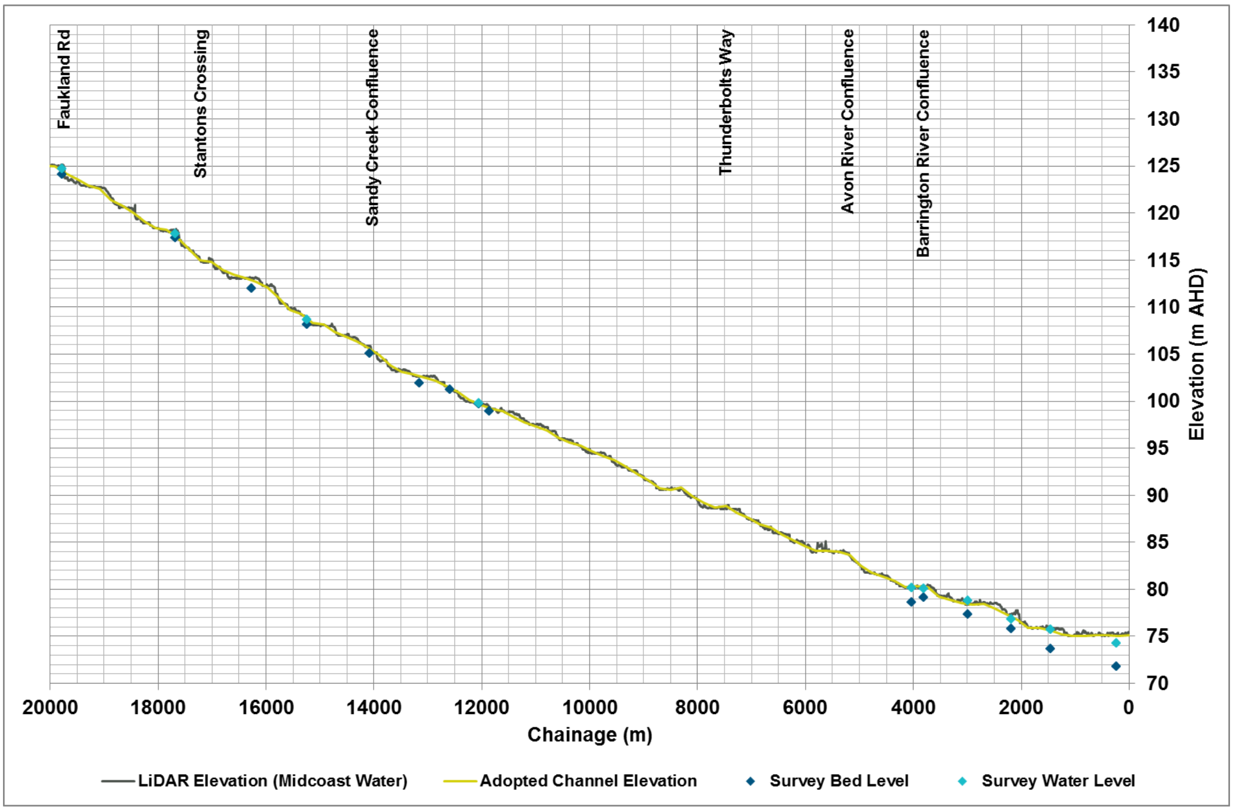


Figure 4-2 Assessment of LiDAR Survey Representation of Gloucester River Channel Topography

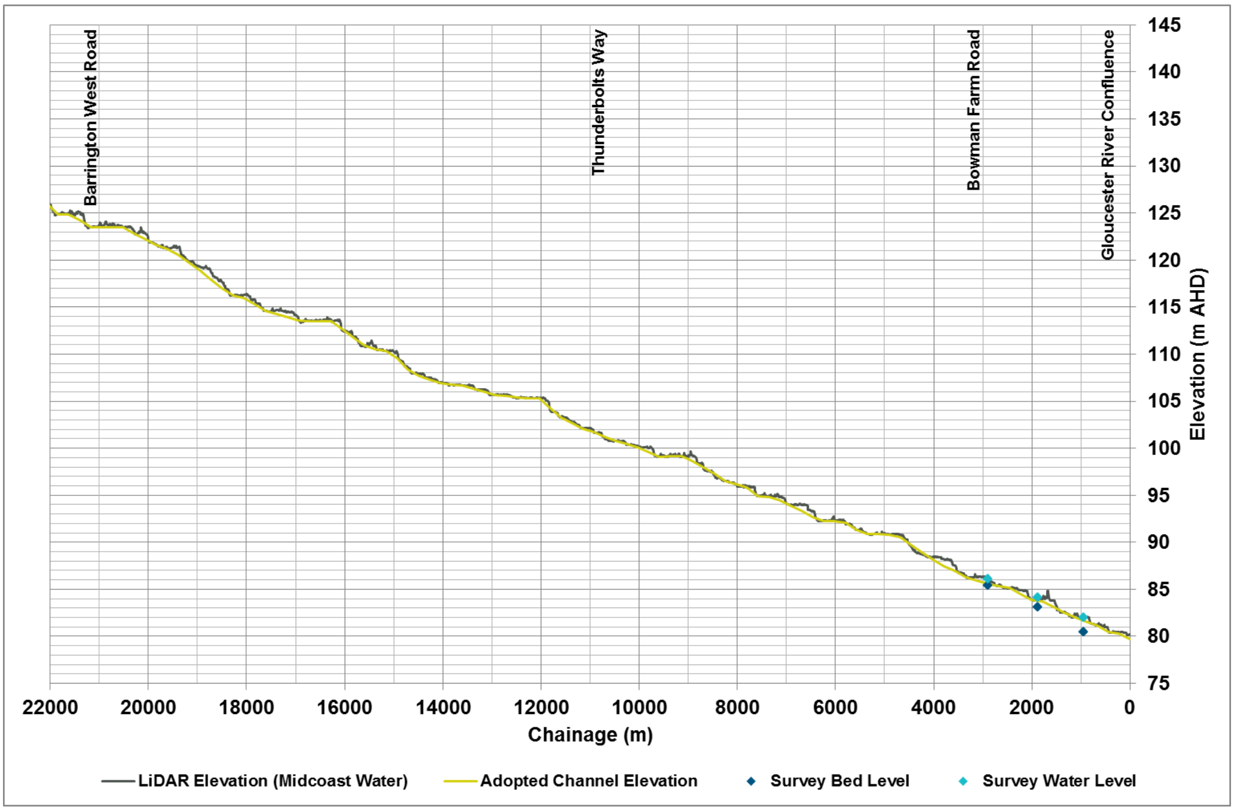


Figure 4-3 Assessment of LiDAR Survey Representation of Barrington River Channel Topography

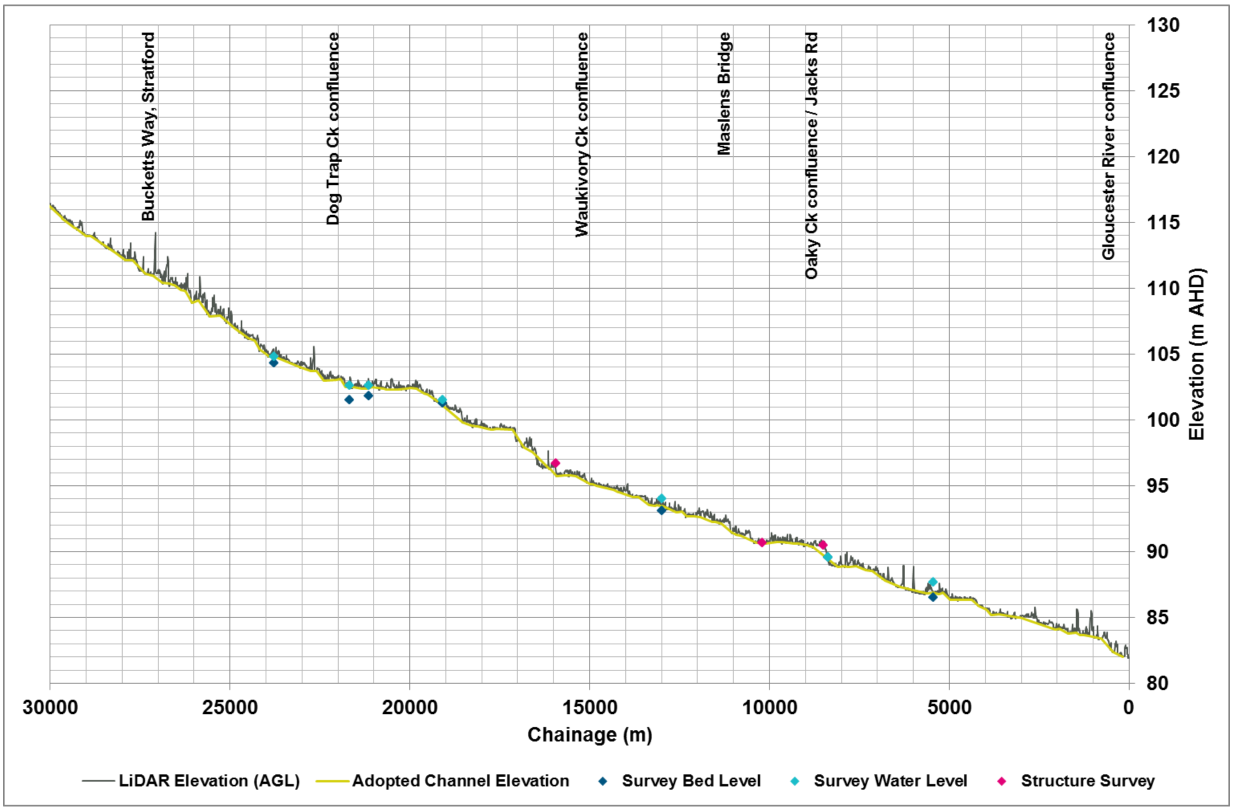


Figure 4-4 Assessment of LiDAR Survey Representation of Avon River Channel Topography

The sensitivity of modelled flood levels to the adopted channel profile was tested. The 1% AEP design flood event was simulated and changes in modelled channel elevation of up to 0.5m only resulted in differences in peak flood level in the order of a few centimetres. Given that a full channel survey at the required interval of 200m – 500m would be very costly and that the impacts of incorporating this into the hydraulic model would have a minimal impact on the flood study outcomes, it was recommended not to undertake any additional survey. The existing datasets of LiDAR and survey marks were deemed to provide a sufficient representation of the channel topography for use in this study.

An existing property floor level survey was available from the previous studies and was utilised for the flood damages assessment. This covered the majority of the flood affected properties for the modelled design events except the PMF and the acquisition of additional survey was therefore deemed of limited value to the outcome of the study. For properties located outside of the existing survey dataset an estimate of floor level was made using the LiDAR ground surface elevations.

5 Model Development

Computer models are the most accurate, cost-effective and efficient tools to assess a catchment's flood behaviour. For this study, two types of models were used:

- A hydrologic model of the upper Gloucester River catchment, including contributing catchments of the Barrington River and Avon River (total area of around 1250 km^2); and
- A hydraulic model covering the floodplain of the study catchment, including the Barrington River, Gloucester River, Avon River, Oaky Creek, Waukivory Creek and Dog Trap Creek (total area of around 220 km^2).

The **hydrologic model** simulates the catchment rainfall-runoff processes, producing the river/creek flows which are used in the hydraulic model.

The **hydraulic model** simulates the flow behaviour of the channel and floodplains, producing flood levels, flow discharges and flow velocities.

Both of these models were calibrated interactively.

Information on the topography and characteristics of the catchments, watercourses and floodplains are built into the models. Recorded historical flood data, including rainfall, flood levels and river flows, are used to simulate and validate (calibrate and verify) the models. The models produce as output, flood levels, flows (discharges) and flow velocities.

Development of a hydraulic model follows a relatively standard procedure:

1. Discretisation of the catchment, watercourses, floodplain, etc.
2. Incorporation of physical characteristics (river cross-sections, floodplain levels, structures etc).
3. Establishment of hydrographic databases (rainfall, river flows, flood levels) for historic events.
4. Calibration to one or more historic floods (calibration is the adjustment of parameters within acceptable limits to reach agreement between modelled and measured values).
5. Verification to one or more other historic floods (verification is a check on the model's performance without further adjustment of parameters).
6. Sensitivity analysis of parameters to measure dependence of the results upon model assumptions.

Once model development is complete it may then be used for:

- Establishing design flood conditions;
- Determining levels for planning control; and
- Modelling development or management options to assess the hydraulic impacts.

5.1 Hydrological Model

The hydrologic model simulates the rate at which rainfall runs off the catchment. The amount of rainfall runoff and the attenuation of the flood wave as it travels down the catchment is dependent on:

- The catchment slope, area, vegetation and other characteristics;
- Variations in the distribution, intensity and amount of rainfall; and
- The antecedent conditions (dryness/wetness) of the catchment.

These factors are represented in the model by:

- Sub-dividing (discretising) the catchment into a network of sub-catchments inter-connected by channel reaches representing the watercourses. The sub-catchments are delineated, where practical, so that they each have a general uniformity in their slope, landuse, vegetation density, etc;
- The amount and intensity of rainfall is varied across the catchment based on available information. For historical events, this can be very subjective if little or no rainfall recordings exist.
- The antecedent conditions are modelled by varying the amount of rainfall which is “lost” into the ground and “absorbed” by storages. For very dry antecedent conditions, there is typically a higher initial rainfall loss.

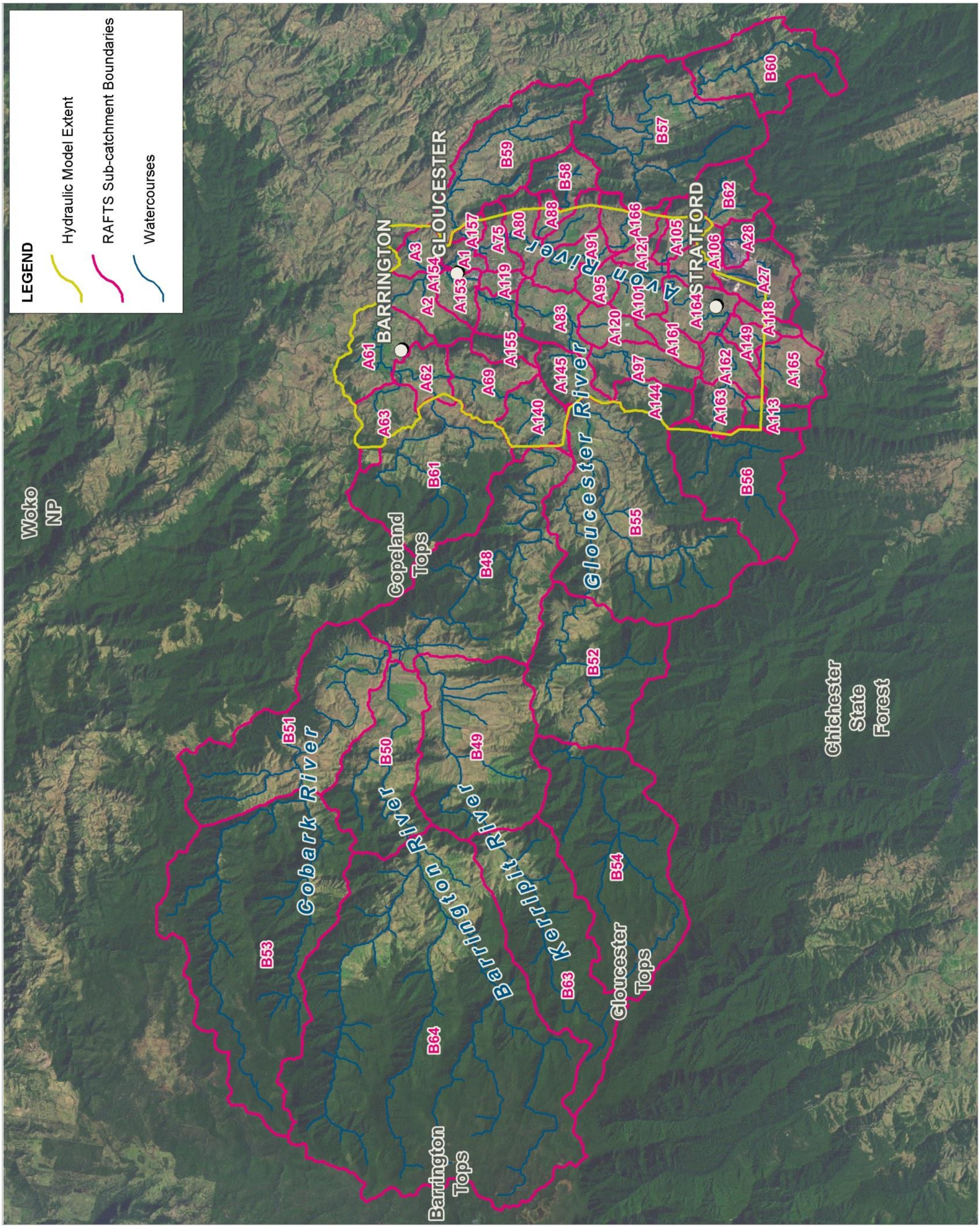
The output from the hydrologic model is a series of flow hydrographs at selected locations such as at the boundaries of the hydraulic model. These hydrographs are used by the hydraulic model to simulate the passage of the flood through the catchment.

The XP-RAFTS software was used to develop the hydrologic model using the physical characteristics of the catchment including catchment areas, ground slopes and vegetation cover as detailed in the following sections.

5.1.1 Flow Path Mapping and Catchment Delineation

The Barrington River and Gloucester River catchments drain approximately 590 km^2 and 200 km^2 respectively into the hydraulic model area. In order to accurately represent the rate and volume of runoff generated from the Barrington and Gloucester catchments to be fed into the hydraulic model, it was important to delineate the catchments appropriately. The hydrological model was split into a coarse network of sub-catchments outside the study area extent, and was refined further within the study area to provide sufficient detail of local catchment inflows as shown in Figure 5-1.

Table 5-1 summarises the key catchment parameters adopted in the XP-RAFTS model, including catchment area, vectored slope and PERN (roughness) value estimated from the available topographic information and aerial photography. The adopted PERN values considered if the majority of the sub-catchment could be described as either forested area (PERN of 0.12) or cleared/pasture area (PERN of 0.06).



Title:

RAFTS Model Sub-catchment Layout

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Table 5-1 RAFTS Sub-catchment Properties

ID	Area (ha)	Slope (%)	PERN	ID	Area (ha)	Slope (%)	PERN	ID	Area (ha)	Slope (%)	PERN
A1	301	0.78	0.06	A113	483	5.14	0.12	A166	696	0.95	0.06
A2	916	1.53	0.06	A115	964	0.94	0.06	B48	6640	0.58	0.09
A3	486	1.17	0.06	A118	280	1.03	0.06	B49	5540	1.26	0.08
A27	193	3.57	0.06	A119	247	0.75	0.06	B50	3480	1.01	0.08
A28	502	7.52	0.06	A120	582	1.01	0.06	B51	5600	1.11	0.08
A61	1510	0.53	0.06	A121	250	0.95	0.06	B52	4500	1.7	0.09
A62	732	0.73	0.06	A140	1020	0.85	0.06	B53	10800	3.48	0.12
A63	926	1.81	0.06	A144	704	4.03	0.09	B54	6700	3.99	0.12
A69	1200	1.55	0.06	A145	754	1.81	0.06	B55	8340	1.12	0.06
A75	512	0.97	0.06	A149	394	0.54	0.06	B56	3220	4.32	0.12
A80	685	1.51	0.06	A153	541	0.88	0.06	B57	5250	1.22	0.08
A83	1050	0.68	0.06	A154	48	0.00	0.06	B58	789	3.79	0.06
A88	275	2.31	0.06	A155	451	2.01	0.09	B59	2120	0.97	0.06
A90	498	1.21	0.06	A156	500	1.13	0.06	B60	2500	0.9	0.08
A91	747	0.34	0.06	A157	180	1.98	0.06	B61	4380	1.87	0.06
A95	428	0.39	0.06	A161	454	1.44	0.06	B62	1020	3.6	0.06
A97	1090	1.09	0.06	A162	659	0.76	0.06	B63	5330	4.29	0.12
A101	732	0.48	0.06	A163	691	1.76	0.06	B64	21800	3.05	0.12
A105	581	1.13	0.06	A164	916	0.17	0.06				
A106	623	0.42	0.06	A165	1070	1.46	0.06				

As indicated in the table and evident from aerial photography, the greater proportion of the upper Barrington catchment is densely vegetated. The lower Barrington, Gloucester and Avon catchments are predominantly cleared land uses.

5.1.2 Rainfall Data

Rainfall information is the primary input and driver of the hydrological model, which simulates the catchments response in generating surface run-off. Rainfall characteristics for both historical and design events are described by:

- Rainfall depth – the depth of rainfall occurring across a catchment surface over a defined period (e.g. 270mm in 36hours or average intensity 7.5mm/h); and
- Temporal pattern – describes the distribution of rainfall depth at a certain time interval over the duration of the rainfall event.

Both of these properties may vary spatially across the catchment.

The procedure for defining these properties is different for historical and design events. For historical events, the recorded hyetographs at continuous rainfall gauges provide the observed rainfall depth and temporal pattern. Where only daily read gauges are available within a catchment, assumptions regarding the temporal pattern may need to be made.

For design events, rainfall depths are most commonly determined by the estimation of intensity-frequency-duration (IFD) design rainfall curves for the catchment. Standard procedures for derivation of these curves are defined in AR&R (2001). Similarly AR&R (2001) defines standard temporal patterns for use in design flood estimation.

The rainfall inputs for the historical calibration/validation events are discussed in further detail in Section 6.

5.2 Hydraulic Model

BMT WBM has applied the fully 2D software modelling package TUFLOW. The 2D model has distinct advantages over 1D and quasi-2D models in applying the full 2D unsteady flow equations. This approach is necessary to model the complex interaction between watercourses and floodplains and converging and diverging of flows through structures. The channel and floodplain topography is defined using a high resolution DEM for greater accuracy in predicting flows and water levels and the interaction of in-channel and floodplain areas.

5.2.1 Topography

The ability of the model to provide an accurate representation of the flow distribution on the floodplain ultimately depends upon the quality of the underlying topographic model. For this study, a 2m by 2m gridded DEM was derived from the LiDAR survey datasets provided by Council.

As discussed in Section 4, other available survey information was used to validate the appropriateness of the DEM to provide adequate representation of the channel topography. This includes the ground survey cross sections for the Gloucester and Barrington River and channel bed survey for the Avon River. The channel topography has been incorporated into the 2D model representation and is discussed further in Section 5.2.4.

5.2.2 Extents and Layout

Consideration needs to be given to the following elements in constructing the model:

- Topographical data coverage and resolution;
- Location of recorded data (eg. levels/flows for calibration);
- Location of controlling features (eg. dams, levees, bridges);
- Desired accuracy to meet the study’s objectives; and
- Computational limitations.

With consideration to the available survey information and local topographical and hydraulic controls, a 2D model was developed extending from just downstream of the naturally occurring bottleneck known as “Old Black Ridge” (downstream of the confluence area), upstream along the major tributary routes of the Barrington, Gloucester and Avon Rivers. The upstream extent of the model terminates at the location of stream flow gauges along the Barrington River at Forbesdale and the Gloucester River at Forbesdale. The model incorporates the entire cleared floodplain area for the Avon River, modelling 40km in length of the Avon River. The area modelled within the 2D domain comprises a total area of some 220km^2 which represents around 76% of the Avon River catchment and approximately 18% of the combined Barrington, Gloucester and Avon River catchment area included within the hydrological model.

A TUFLOW 2D domain model resolution of 8m was adopted for study area. It should be noted that TUFLOW samples elevation points at the cell centres, mid-sides and corners, so an 8m cell size results in DEM elevations being sampled every 4m. This resolution was selected to give necessary detail required for accurate representation of floodplain and channel topography and its influence on overland flows. It also considers the need to largely restrict modelled depths as being less than the cell width and to achieve model simulations within a reasonable run time.

5.2.3 Hydraulic Roughness

The development of the TUFLOW model requires the assignment of different hydraulic roughness zones. These zones are delineated from aerial photography and cadastral data identifying different land-uses (e.g. forest, cleared land, roads, urban areas, etc.) for modelling the variation in flow resistance.

The hydraulic roughness is one of the principal calibration parameters within the hydraulic model and has a major influence on flow routing and flood levels. The roughness values adopted from the calibration process is discussed in Section 6.

5.2.4 Channel Network

The study required the modelling of the Barrington, Gloucester and Avon Rivers and other major watercourses to the limits of the cleared floodplain areas. For the modelled watercourses, representative channel elevations were defined using the digitised centrelines and methods described in Section 4. This approach was used to embed the channel topography into the 2D domain of the TUFLOW model. Embedding the channel topography within the 2D model domain provides several advantages over a 1D channel representation, including:

- A smoother transition between channel and floodplain conveyance;
- A more spatially rich representation of the high-flow in-channel flood conveyance, taking account of local topographic controls both at and beneath bank-full level;
- An inherent representation of the channel sinuosity;
- Spatial variation of velocities across the width of the channel; and
- Improved flood mapping output for in-channel areas.

A sample cross section of the Gloucester River channel, derived from LiDAR data and other survey data is provided in Figure 5-2. Generally, the methods detailed in Section 4 to modify the channel bed results in flow areas of the modelled channel profiles similar to those represented in the LiDAR data, shown in Figure 5-2.The frequency of available survey marks increase at the downstream end of the model, closer to Gloucester town. It should be noted that due to the location of many of these survey marks in naturally occurring pools along the channel reach, the difference between surveyed water level and surveyed bed elevation is significant. As such, the LiDAR data through these lower reaches on the Gloucester River and Barrington River is expected to be representative of the water surface. Sensitivity testing was performed to assess the impact of raising and lowering the bed elevation and was found to have little impact on modelled flood levels, largely due to the volume of floodplain conveyance compared to in-channel flow capacity. Details of this testing can be found in Section 8.6.3.

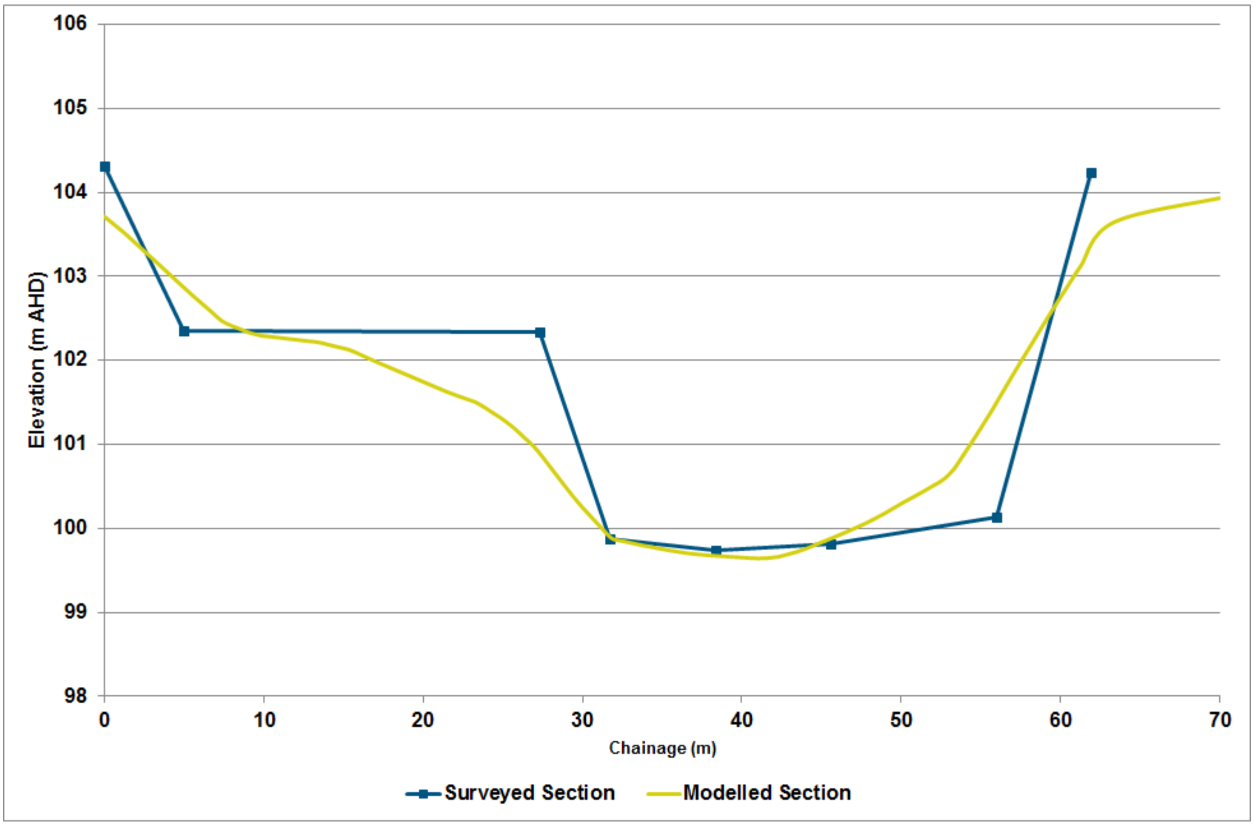
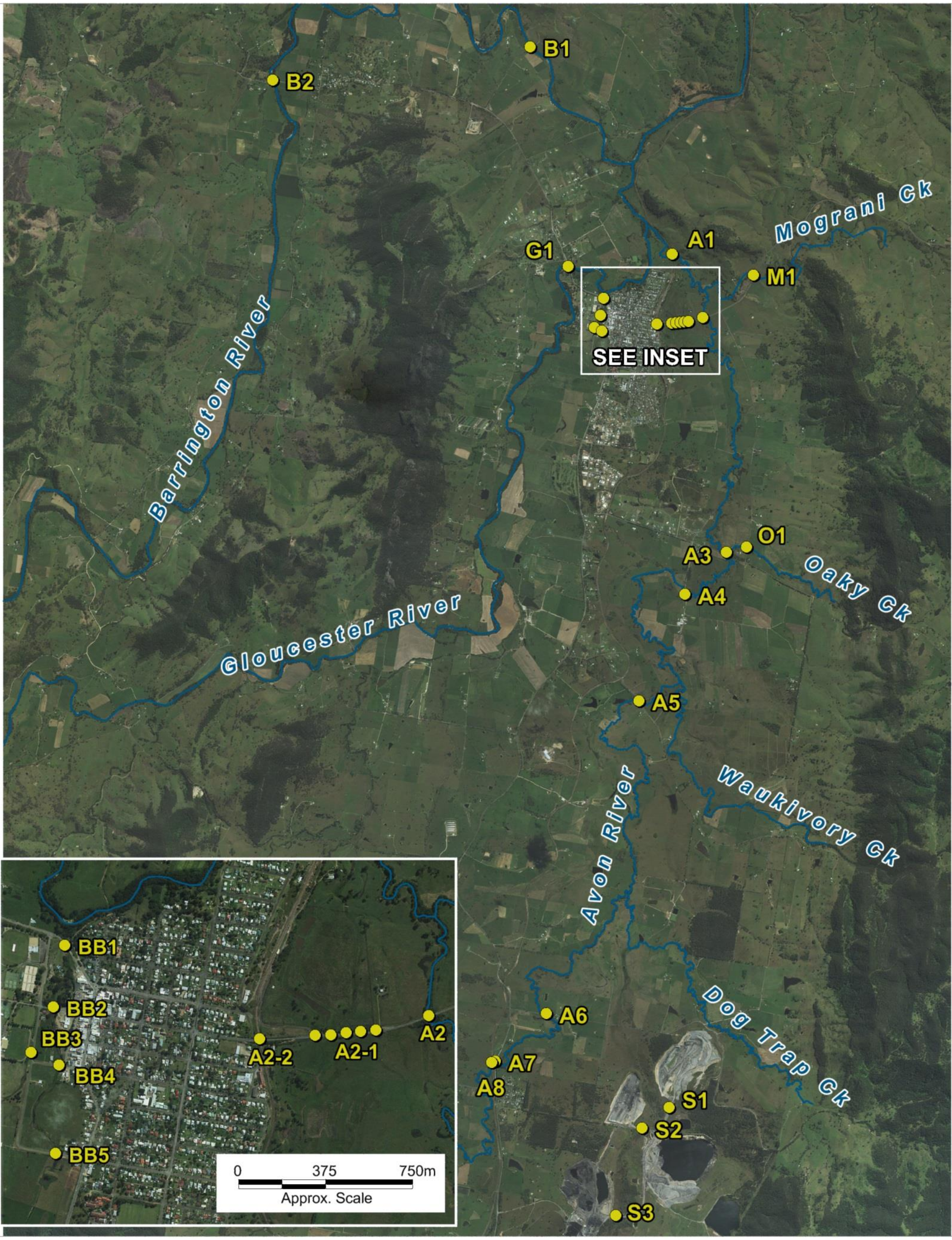


Figure 5-2 Sample Cross Section of LiDAR Derived Channel Topography

5.2.5 Structures

There are a number of bridge and culvert crossings over the watercourses within the model extents as detailed in Table 5-2 (refer to Figure 5-3 for locations). These structures vary in terms of construction type and configuration, with varying degrees of influence on local hydraulic behaviour. Incorporation of these major hydraulic structures in the model provides for simulation of the hydraulic losses associated with these structures and their influence on peak water levels within the study area.

The larger bridge structures have been modelled as flow constrictions within the 2D domain. This utilises the layered flow constriction option available in TUFLOW, which represents the bridge superstructure and losses. Obvert levels, road crests and hand rail obstruction details are entered along with additional form losses. Culverts, which are typically smaller, have been modelled using 1D structures, embedded within the 2D domain. The structure details including invert levels and opening dimensions are specified. Bridge overtopping is represented in the 2D domain.



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Modelled Structure Locations

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Table 5-2 Modelled Hydraulic Structures

ID	Location	Structure
B1	Bowman Farm Rd, Barrington River	Concrete bridge (approx 90m span)
B2	Thunderbolts Way, Barrington River	Timber bridge (approx 80m span)
G1	Thunderbolts Way, Gloucester River	Concrete bridge (approx 50m span)
A1	Railway (Gloucester), Avon River	Concrete bridge (approx 200m span)
A2	Bucketts Way (Gloucester), Avon River	Concrete bridge (approx 55m span)
A2-1	Bucketts Way (Gloucester), Avon River floodplain	Concrete culverts (four 3m x 1.6m box)
A2-2	Bucketts Way Rail Overpass, Gloucester town	Concrete bridge (approx 20m span)
A3	Jacks Rd, Avon River	Timber bridge (approx 25m span)
A4	Maslens Ln, Avon River	Timber bridge (approx 25m span)
A5	Fairbairns Rd, Avon River	Concrete bridge (approx 10m span)
A6	Wenham Cox Rd, Avon River	Two timber bridges (approx 30m span)
A7	Bucketts Way (Stratford), Avon River	Concrete bridge (approx 20m span)
A8	Railway (Stratford), Avon River	Concrete bridge (approx 60m span)
BB1	Park St, The Billabong	Concrete bridge (approx 60m span)
BB2	Denison St, The Billabong	Concrete bridge (approx 30m span)
BB3	Boundary St, The Billabong	Conrete culvert (three 1.6m x 0.9m box)
BB4	Hume St, The Billabong	Concrete culvert (double 0.6m pipe)
BB5	Philip St, The Billabong	Concrete bridge (two 6.2m x 1.2m arches)
M1	Bucketts Way, Mograni Creek	Concrete culvert (double 0.45 pipe)
O1	Waukivory Rd, Oaky Creek	Bridge (approx 30m span)
S1	Bowens Rd, Stratford Mine Site	Concrete culvert (three 3.5m x 1.2m box)
S2	Bowens Rd, Stratford Mine Site	Concrete culvert (double 3m pipe)
S3	Bowens Rd, Stratford Mine Site	Concrete culvert (single 1.5m pipe)

5.2.6 Boundary Conditions

The catchment runoff is determined through the hydrological model and is applied to the TUFLOW model as flow vs. time inputs. These are applied at the upstream modelled watercourse limits and also as distributed inflows along the modelled watercourse reaches.

At the downstream limit, a constant water level was assigned to the boundary. This approach was determined to be appropriate for this study as a constant water level improved model stability. For calibration events an approximate downstream boundary was selected from recorded flood marks. The methods used to assign the water level at the boundary for design events is detailed in Section 7.5.

6 Model Calibration

6.1 Selection of Calibration Events

The selection of suitable historical events for calibration of computer models is largely dependent on available historical flood information. Ideally the calibration and validation process should cover a range of flood magnitudes to demonstrate the suitability of a model for the range of design event magnitudes to be considered.

Since records began in 1952, the two largest floods experienced in Gloucester occurred in 1956 and 1978, as detailed in Section 2. Due to the scarcity of calibration data available for these events, notably any continuous rainfall records to appropriately define temporal patterns of storms and stream flow gauges to compare discharge rates, there was need to select a more recent event where sufficient calibration data was available.

The June 2011 flood event is the largest of the significant recent events to have occurred within the study area. Given the abundance of data available for model inputs and calibration, particularly within the Avon River catchment, as detailed in a number of recent studies within the area, it has been selected as the principal calibration event for the models. The February 2013 also generated a reasonable flood response within the catchment but was not as large as that in June 2011. It has also been selected for model calibration given the relative availability of data. The February 2012 event was the smallest of the three recent floods but has not been selected for model calibration as it was no larger than a 50% AEP magnitude and as such is restricted in its suitability.

The February 1929 event was the largest flood known to have occurred within the Gloucester township. Given there is reasonable coverage of historical data available for this event, in the form of recorded flood levels, daily rainfall data, historical photographs and anecdotal evidence, this was selected as a further validation event.

The model calibration is based on the following events, due to the volume of data available:

- June 2011; and
- February 2013.

The following events were used for model verification, given the limited availability of historical data:

- February 1929;
- March 1956;
- March 1978;

The available data, modelling approach and model results for each of these events are discussed in further detail in the following sections. A number of other potential verification events were available, such as 1963, 1974 and 1976, but were not chosen in preference to the above events given their smaller magnitude and limited data availability.

6.2 Channel Roughness

The focus of the model calibration process is essentially to determine the most appropriate set of flow and roughness conditions, in order for the model to be able to reasonably reproduce observed flood behaviour within the catchment. As the observed flood levels are a function of both flows and roughness there are a number of combinations of the two that will produce similar levels. A useful dataset for determining appropriate model roughness values is the gauging station spot gaugings. These are measured combinations of flow and water level. A large number of these at high flow rates will provide a good rating curve (flow vs. level relationship), which can be matched within the model by selecting an appropriate roughness value.

Unfortunately for the stream gauges in the study catchments there is not a large spot gaugings database to work with. The rapid flood response of the catchments means that flood flows are rarely measured. Therefore there is much uncertainty regarding the adopted high flow rating curves at the sites that are used to derive flow rates from the recorded water levels.

A Manning's 'n' of 0.04 was adopted for the channel roughness of the Gloucester and Barrington Rivers. This was based on the most appropriate values from the available literature and previous experience with channels of a similar nature. Roughness values of 0.03 and 0.05 were also tested for model sensitivity purposes.

Two high flow rating curves exist for the Forbesdale gauges – one which was adopted prior to the 2011 flood event and another that was derived from the flow gaugings obtained during the 2011 event. There is some uncertainty regarding the 2011 event spot gaugings. On the Gloucester River the flow was measured at the Gloucester gauge. The same flow value was then transferred upstream to the Forbesdale gauge and the corresponding water level was estimated from an assumed travel time of the flood wave between Forbesdale and Gloucester. On the Barrington River the flow at Forbesdale was gauged accurately for approximately half of the channel and then the total flow for the entire channel was estimated from this measurement.

The modelled rating curves for the Gloucester River at Forbesdale are presented on Figure 6-1. Also shown on the figure are the two high flow rating curves that have been adopted for the gauge site and the available spot gaugings.

The difference between the two site ratings is significant, with the pre-2011 curve producing flows that are almost double those of the post-2011 curve. The modelled rating curves produced from the range of likely roughness values produce much less variation and are reasonably similar to the post-2011 site rating to a level of 127.5m AHD, at which point the flows spill out of bank.

The modelled rating curves for Barrington River at Forbesdale are presented on Figure 6-2. Also shown on the figure are the two high flow rating curves that have been adopted for the gauge site and the available spot gaugings.

The difference between the two ratings is less than that on the Gloucester River, with the pre-2011 curve producing flows around 40% larger than those of the post-2011 curve. The modelled rating curves produced from the range of likely roughness values produce a similar variation to that between the two site ratings. The adopted Manning's 'n' of 0.04 produces a rating curve that sits between the two higher flow spot gaugings.

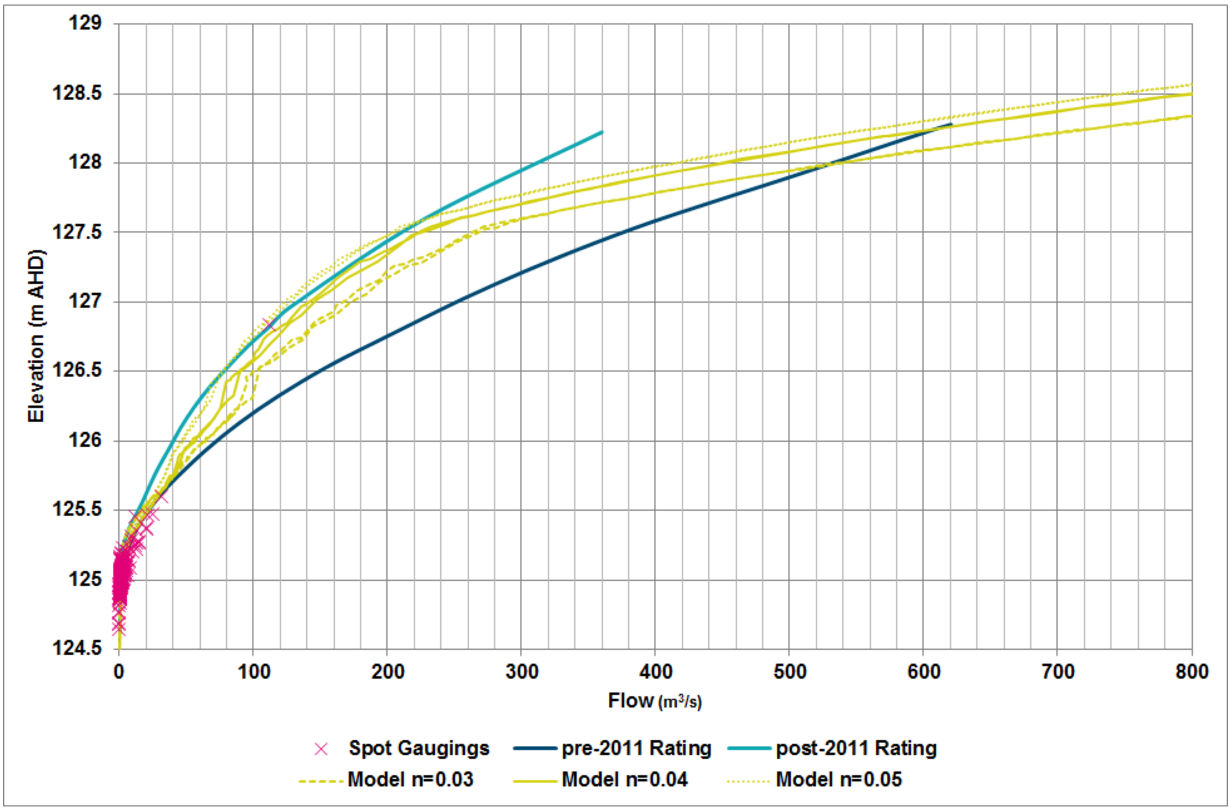


Figure 6-1 Rating Curve Analysis for the Gloucester River at Forbesdale

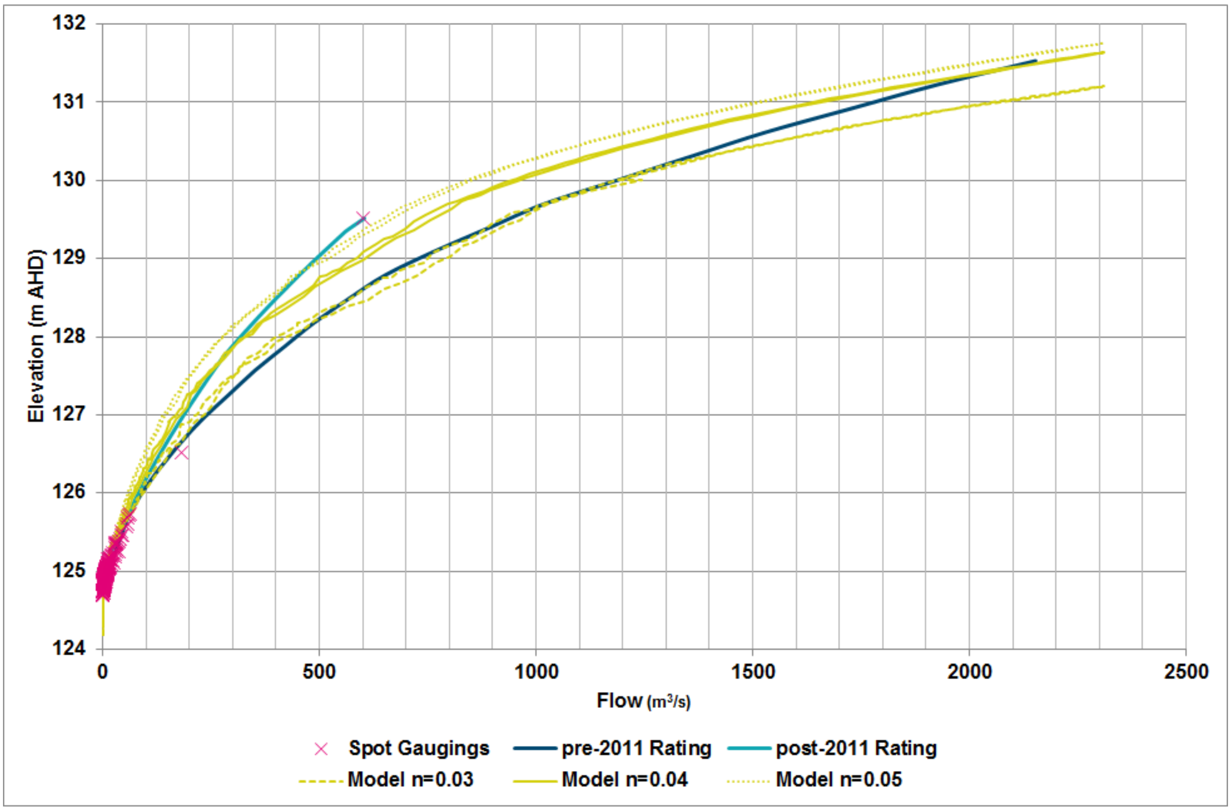


Figure 6-2 Rating Curve Analysis for the Barrington River at Forbesdale

6.3 June 2011 Model Calibration

6.3.1 Rainfall Data

The distribution of rainfall gauge locations in the vicinity of the Barrington, Gloucester and Avon River catchments was presented in Figure 2-17 with their respective periods of record shown in Table 2-6 and Table 2-7. There are a number of gauges located within and around the catchment that recorded daily rainfall totals during the June 2011 event. There are four continuous rainfall gauges located within the vicinity of the study catchments. The location of the local daily and continuous rainfall gauges is presented in Figure 6-3, with daily totals presented in Table 6-1.

Table 6-1 Daily Rainfall Records – June 2011 Event

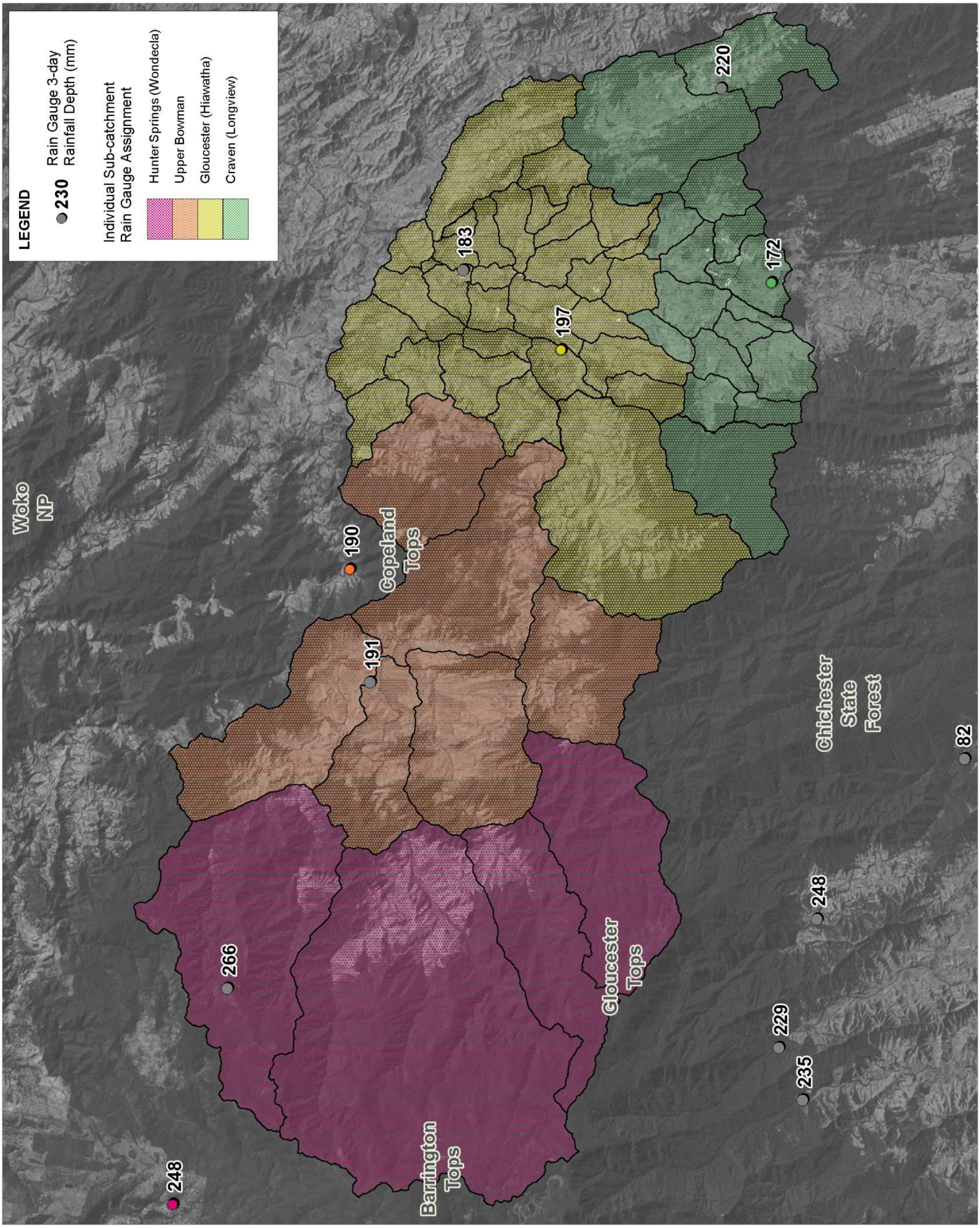
Gauge Location	14th June (mm)	15th June (mm)	16th June (mm)
Hunter Springs (Wondecla)	46	136	66
Moppy Lookout (Barrington Tops)	47	139	80
Cobark	39	99	53
Upper Bowman	35	97	56
Gloucester Post Office	34	77	72
Gloucester (Hiawatha)	33	95	70
Craven (Longview)	11	85	76
Waukivory	31	100	90

The daily rainfall records are reasonably consistent distribution across the study catchments, with around 35mm recorded on the 14th, 100mm on 15th and 70mm on 16th. The two gauges situated within the Barrington Tops (Hunter Springs and Moppy Lookout) recorded around 40% more rainfall on the 14th and 15th than at the other gauges. On the 16th the largest rainfall depth occurred at the far west of the study area (Waukivory), with the least rainfall occurring in the central section (Cobark and Upper Bowman).

The hourly rainfall hyetographs for the continuous gauges on the 14th, 15th and 16th June 2011 rainfall record are presented in Figure 6-4 and Figure 6-5. The gauge at Hunters Springs (Wondecla), located on the western slopes of the Barrington Tops (elevation 1235m AHD) and the Upper Bowman gauge (elevation 280m AHD) exhibit a similar pattern of rainfall, with three distinct bursts of rainfall recorded.

The Gloucester (Hiawatha) and Craven (Longview) gauges also record three bursts of rainfall. During the final burst (rain falling from the 1:00PM – 10:00PM on the 15th) the depth of rainfall recorded by the Gloucester (Hiawatha) and the Craven (Longview) gauge was around 50% more than was recorded by the other two gauges.

Rainfall radar data is available from BoM for this event from the Newcastle radar station at Lemon Tree Passage, around 80km south-east of Gloucester. The radar rainfall data was used to identify whether the rainfall distributions captured by the gauges were representative of conditions across the entire study catchment.



Title:

June 2011 Rain Gauge Distribution and Recorded Rainfall

Figure: **6-3**

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Approx. Scale

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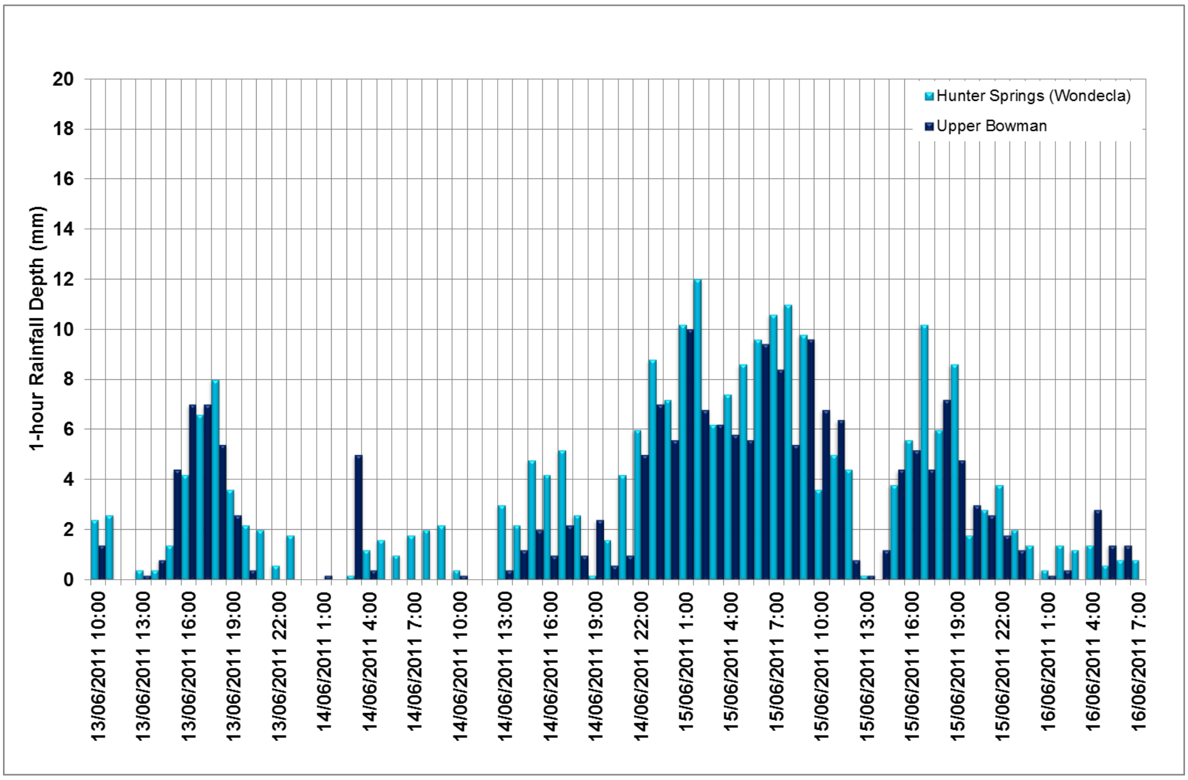


Figure 6-4 1-hour Rainfall Hyetograph for the June 2011 Calibration Event at the Hunter Springs (Wondecla) and Upper Bowman Gauges

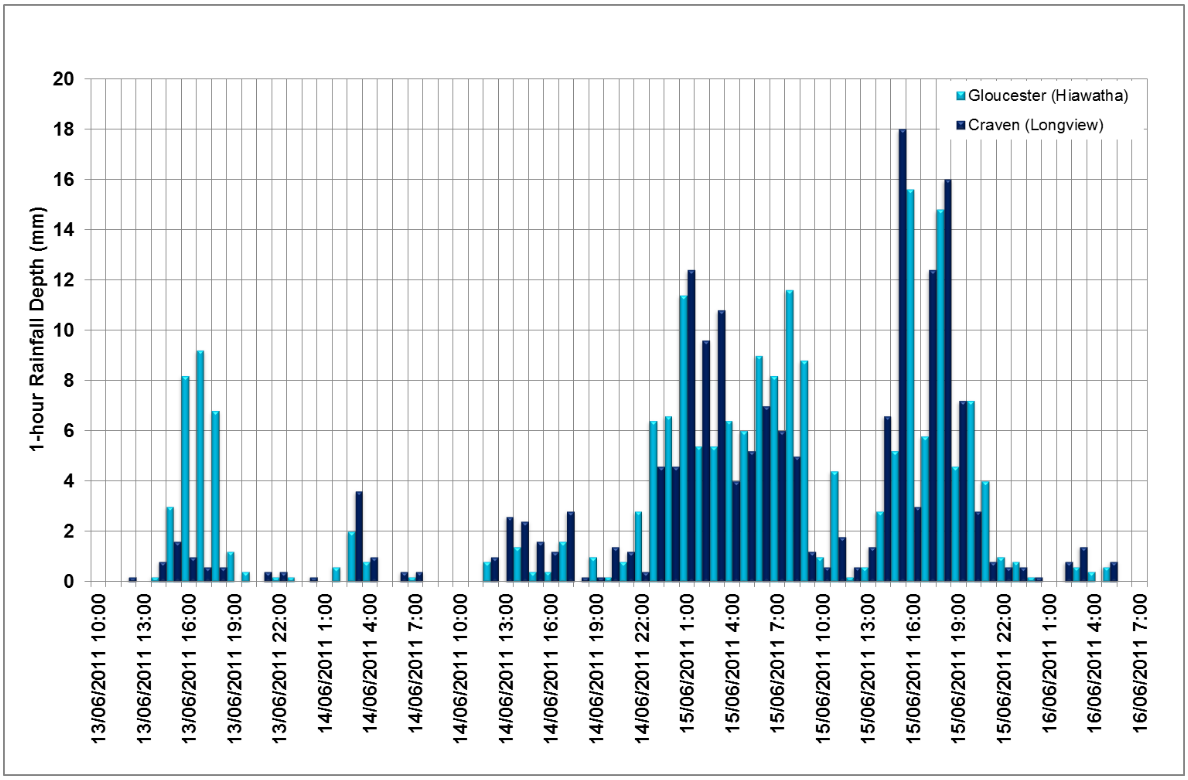


Figure 6-5 1-hour Rainfall Hyetograph for the June 2011 Calibration Event at the Gloucester (Hiawatha) and Craven (Longview) Gauges

Temporal patterns extracted from the radar rainfall data for each sub-catchment were reasonably consistent with those recorded at the rainfall gauges.

The temporal patterns recorded at the four continuous gauges were assigned to each sub-catchment, considering distance from the gauge and the similarity of both elevation and terrain characteristics. The outcome of the sub-catchment allocation is presented in Figure 6-3 where each hydrological sub-catchment has been coloured, indicating the most representative continuous rainfall record for that location.

The limited number of daily rainfall gauges across the catchment provides difficulties in accurately interpolating rainfall totals across the study. Rainfall gauges located on the southern slopes of the Barrington and Gloucester Tops are not necessarily representative of conditions within the study catchments, but have a significant influence on the interpolated rainfall surfaces.

Given this uncertainty, a simple approach was adopted whereby the total rainfall to be applied at each sub-catchment was taken from the closest daily rainfall gauge within the study catchments. For example, with reference to Figure 6-3, the upper sub-catchments of Waukivory Creek were assigned a total rainfall of 220mm (the three day total recorded at the Waukivory gauge), distributed across a three day period according to the temporal pattern recorded at Craven (Longview).

In order to gain an appreciation of the relative intensity and magnitude of the June 2011 event, the recorded rainfall depth for various durations within the storm is compared with the Intensity Frequency Duration (IFD) data across the catchment. The AR&R is in the process of revising the design flood estimate guidelines, and have released updated 2013 IFDs. However, these are currently to be used for sensitivity purposes only and not adopted for design flood estimation, as their appropriate use is linked to the adopted design temporal rainfall patterns (the revision of which is still underway).

Design IFD rainfall curves were obtained from AR&R (2001) based on the 1987 and 2013 datasets, as discussed later in Section 7.2.1. Figure 6-6 presents the recorded June 2011 rainfall intensities against both the 1987 IFDs and 2013 IFDs, for comparison. As the Hunter Springs (Wondecla) gauge and the Upper Bowman gauges are located in different design rainfall catchment zones (see Figure 7-1), an average of the IFDs determined for each zone has been calculated for figure presentation purposes.

Both Figure 6-6 and Figure 6-7 highlight the difference in design rainfall intensities determined by the 1987 or 2013 data, particularly within the upper catchment. Rainfall recorded in the upper catchment (Hunter Springs and Upper Bowman gauges) during the June 2011 storm is fairly consistent with the shape of the design rainfall curves. With reference to the 1987 IFDs, the recorded rainfall depth tracks between the 20% AEP and 50% AEP magnitude at the Hunter Springs gauge and just below a 50% AEP magnitude at the Upper Bowman gauge. Given the reduction in design intensities using the 2013 IFDs, comparison against the recorded depth indicated the June 2011 event was of a rarer occurrence than this, placing the recorded rainfall in the order of a 10% AEP to 5% AEP at the Hunters Springs gauge and around a 20% AEP magnitude at the Upper Bowman gauge.

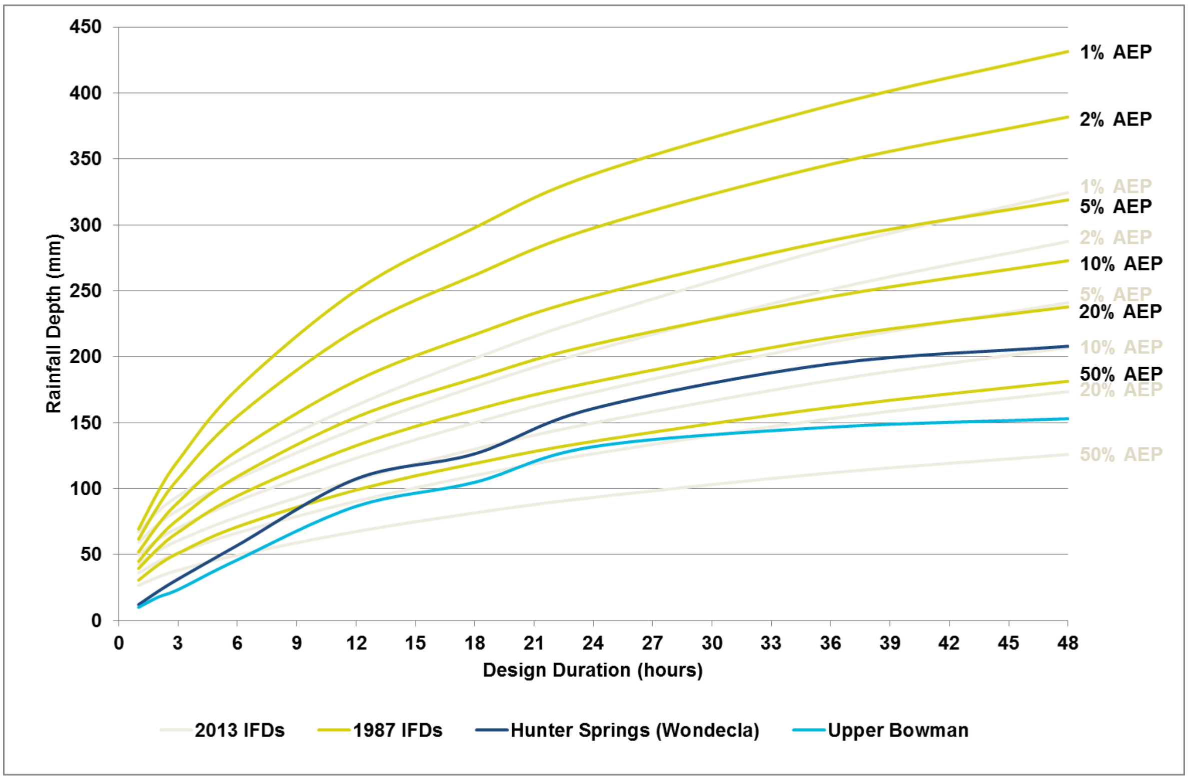


Figure 6-6 Comparison of Recorded June 2011 Rainfall at the Hunter Springs (Wondecla) and Upper Bowman Gauges with IFD Relationships

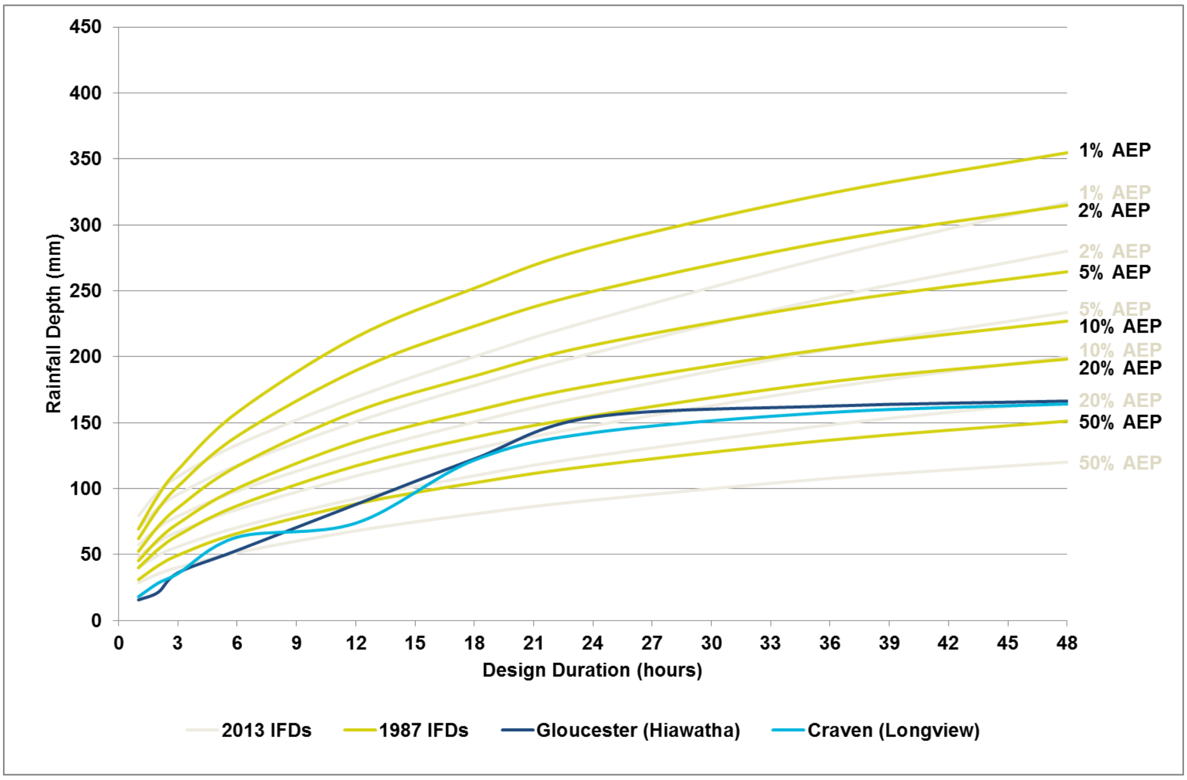


Figure 6-7 Comparison of Recorded June 2011 Rainfall at the Gloucester (Hiawatha) and Craven (Longview) Gauges with IFD Relationships

The similarity in the temporal patterns recorded at the Gloucester and Craven gauges places the recorded depth vs. duration profile for the lower floodplain area around the Gloucester township somewhere between the 50% AEP and 20% AEP magnitude (1987 IFDs), or between the 50% AEP and 20% AEP (2013 IFDs).

6.3.2 Antecedent Conditions

The antecedent catchment condition, reflecting the degree of wetness of the catchment prior to a major rainfall event, directly influences the magnitude and rate of runoff. The initial loss-continuing loss model has been adopted in the RAFTS hydrologic model developed for this study. The initial loss component represents a depth of rainfall effectively lost from the system and not contributing to runoff, and simulates the wetting up of the catchment to a saturated condition. The continuing loss represents the rainfall lost through soil infiltration once the catchment is saturated and is applied as a constant rate (mm/h) for the duration of the runoff event.

Typical design loss rates applicable for eastern NSW catchments are initial loss of 10 to 35 mm and continuing loss of 2.5mm/h (AR&R, 2001). For historical events however, the initial loss is indicative of the catchment wetness and prior rainfall to the modelled storm burst.

Daily rainfall records indicate that averages of around 10mm and 20mm were recorded across the catchment in the 24 hours to 9am the 12th and 13th June 2011 respectively. In the ten days prior, little to no rainfall was recorded. An initial loss of 0mm has been adopted for the model calibration, as it was assumed the rainfall on the 12th and 13th would have accounted for the initial loss of this rainfall event.

6.3.3 Downstream Boundary Condition

No information was available to establish a flood level at the downstream boundary. However, the flood event is of too small a magnitude for the boundary condition to influence flood levels at Gloucester.

6.3.4 Adopted Model Parameters

Having established an appropriate hydraulic roughness for the Gloucester and Barrington River channels (see Section 6.2), the focus of the June 2011 model calibration for those catchments was to achieve a representative hydrological model response at the Forbesdale gauges. Both the hydrological model response and channel roughness was considered to reproduce the observed flood response within the Avon River catchment.

The final values adopted, as shown in Table 6-2 were found to give a good result in representing the recorded water level hydrographs at the stream flow gauges located along the Barrington Gloucester and Avon Rivers, which is discussed further in Section 6.3.5. The adopted parameters also provided a good match to the flood levels indicated by the available flood photographs.

6.3.5 Observed and Simulated Flood Behaviour

The effectiveness of the models to represent the catchment response to the recorded 2011 rainfall can be assessed through comparison of the recorded and modelled hydrographs at the various water level gauging stations within the catchment. Given the uncertainty surrounding appropriate rating curves at the gauges, this comparison has been undertaken using water levels. The analysis of the rating curves at the gauge sites and the consequent derivation of an appropriate Manning's 'n' to represent channel roughness is detailed in Section 6.2.

Table 6-2 June 2011 Adopted Model Parameters

Parameter	Value
Initial Loss (mm)	0
Continuing Loss (mm/hr)	2.5
PERN *Forested* *Cleared*	 0.12 0.06
Bx (storage routing parameter)	1.0
Manning's n (channel) *Barrington River and Gloucester River* *Avon River and Waukivory Creek*	 0.04 0.12
Manning's n (floodplain)	0.06

Stream flow gauges located on the Barrington River at Forbesdale and on the Gloucester River at Forbesdale are available for each of the selected calibration and verification events (except 1929). For the 2011, 2012 and 2013 events, there are additional gauges located on the Barrington River at Relfs Road, the Gloucester River at Gloucester (the site of the old Lehman's Flat bridge) and on the Avon River downstream of Waukivory Creek. Each of these gauges is operated by NSW Office of Water. Additional stream flow gauges are located on the Avon River and along Waukivory Creek and are operated by AGL and GRL respectively.

The hydraulic model extends upstream to include both the Forbesdale gauges. This provides a means to assess whether the inflow from the hydrological model can adequately replicate water level hydrographs observed at the gauges.

The flow hydrographs were extracted from the hydrological model at the Forbesdale gauges and were input as inflow boundaries to the hydraulic model upstream of the gauging sites. The modelled peak flow rates at the two Forbesdale gauges are presented in Table 6-3.

Table 6-3 Modelled Peak Flow Rates at the Forbesdale Gauges for the June 2011 Event

Gauge Location	Peak Flow Rate (m^3/s)
Barrington River at Forbesdale	720
Gloucester River at Forbesdale	235

Figure 6-8 and Figure 6-9 show the modelled water levels at the Barrington River at Forbesdale and the Gloucester River at Forbesdale gauges respectively, against the recorded data for the June 2011 event. The model provides a good representation of the hydrograph shape in terms of timing and peak flood levels, with peak flood levels within 0.1m. The volume of the hydrograph is reasonably represented, however the flood recedes at a faster rate than was recorded during the event. This underestimation of flood volume was generally observed at all gauges within the Barrington and Gloucester catchment and for all events, but to varying degrees.

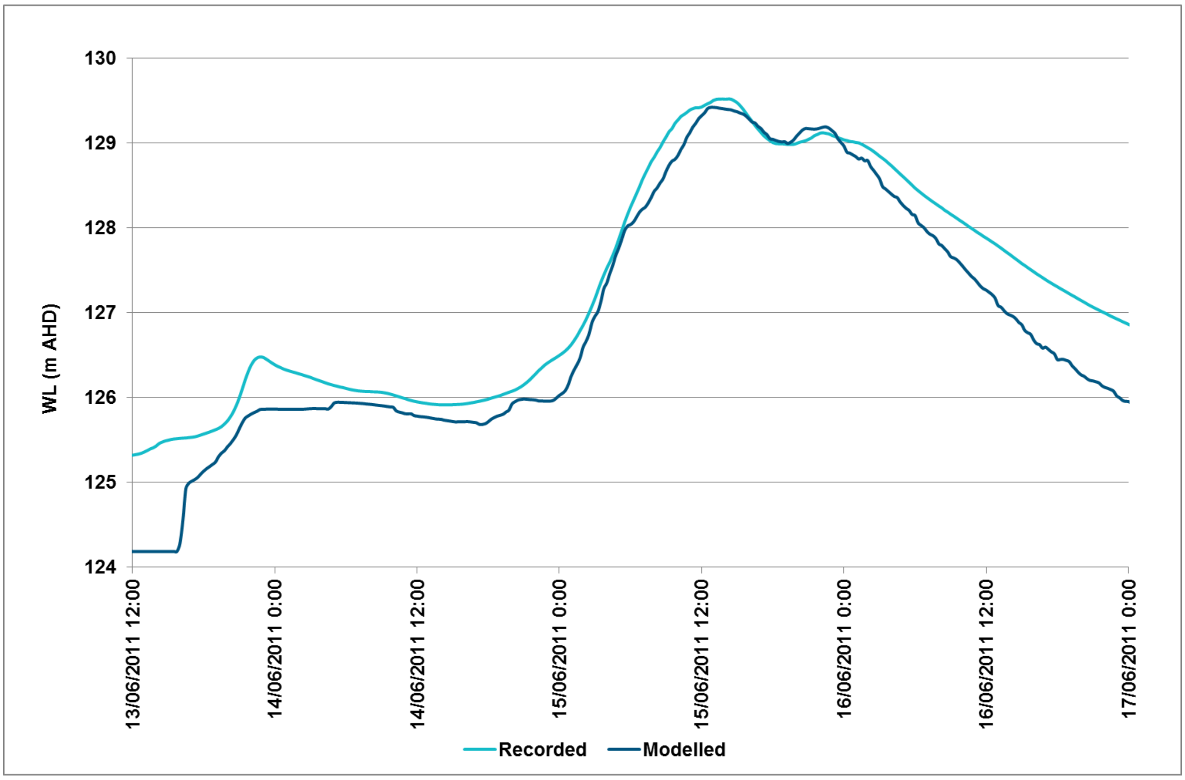


Figure 6-8 Comparison of Recorded and Modelled Water Levels at the Barrington River at Forbesdale Gauge for the June 2011 Event

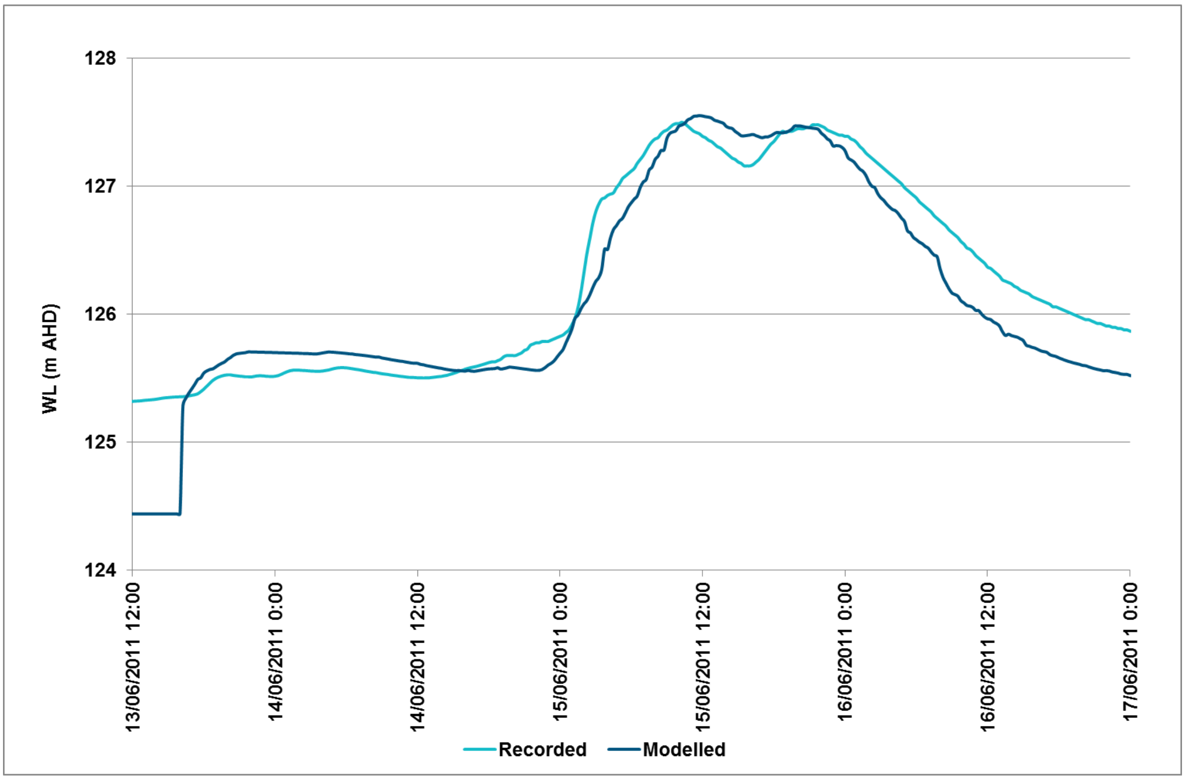


Figure 6-9 Comparison of Recorded and Modelled Water Levels at the Gloucester River at Forbesdale Gauge for the June 2011 Event

The difference was more pronounced the longer the duration of the event, indicating that the interflow component of the stream discharge may be significant in the study catchments. The difference in water levels at the onset of the event is due to the model being dry, whereas in reality a small baseflow exists.

The recorded vs. modelled water level hydrograph further downstream at the Relfs Road gauge is presented in Figure 6-10. Here the model representation of the recorded water level hydrograph differs significantly for the recorded level, with modelled levels up to 1m below those recorded during the event. This proved to be a consistent issue between various events. Modelling of the February 2012 event also demonstrated that if a match to peak water level was achieved at the Barrington River at Forbesdale gauge, the resulting peak flood level recorded at Relfs Road was again underestimated by approximately 1m.

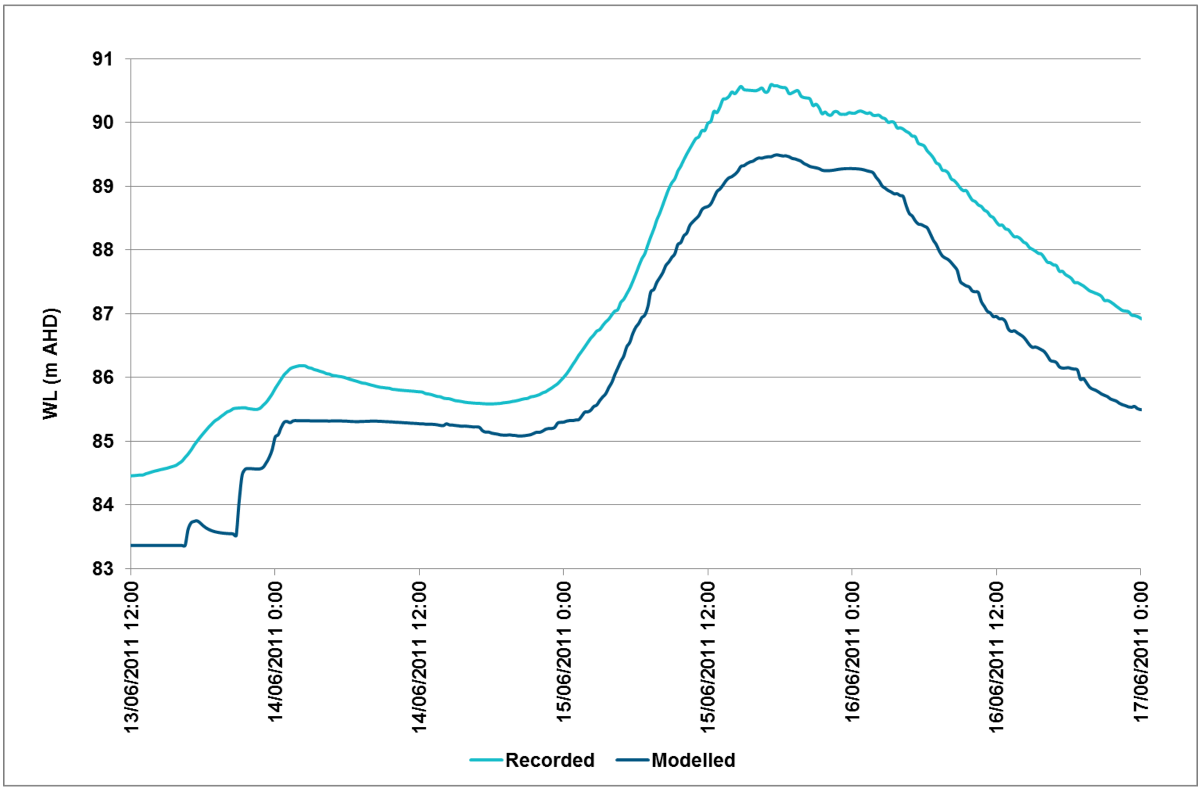


Figure 6-10 Comparison of Recorded and Modelled Water Levels at the Barrington River at Relfs Road Gauge for the June 2011 Event

From the modelled rating curve at the Relfs Road gauge, a flow rate of around 1100m^3/s is required at the gauge to generate a peak water level to match the recorded peak of 90.5m AHD. The modelled flow rate at the Forbesdale gauge is 720m^3/s and indicates the flow rate would have to increase by more than 50% from Forbesdale to Relfs Road. Based on the relative catchment areas upstream of the Forbesdale gauge (~590km^2) and between Forbesdale and Relfs Rd (105km^2), an increase in flow rate of this magnitude from local catchment inflows alone is unlikely.

Given the errors associated with gauge locations, gauge elevations and datum conversions encountered across the study area (including at this gauge), uncertainty regarding exact site information (e.g. zero gauge RL) could account for the repeated underestimation in modelled peak flood level at the Relfs Road gauge. Given that the modelled water level at Relfs Road is consistently under-estimating the recorded levels by a similar level throughout the full range of flow conditions, a potential datum error appears likely.

The peak flood level modelled at the Gloucester River at Gloucester gauge is slightly below the recorded level. Figure 6-11 shows the modelled peak water level at the gauge falls short of the recorded water level hydrograph by around 0.2m for the first peak and around 0.4m for the second peak. The second peak is not as well represented and it is likely that the additional volume observed during the recession of the flood hydrograph at both Forbesdale gauges is resulting in the underestimation on water levels at the Gloucester gauge.

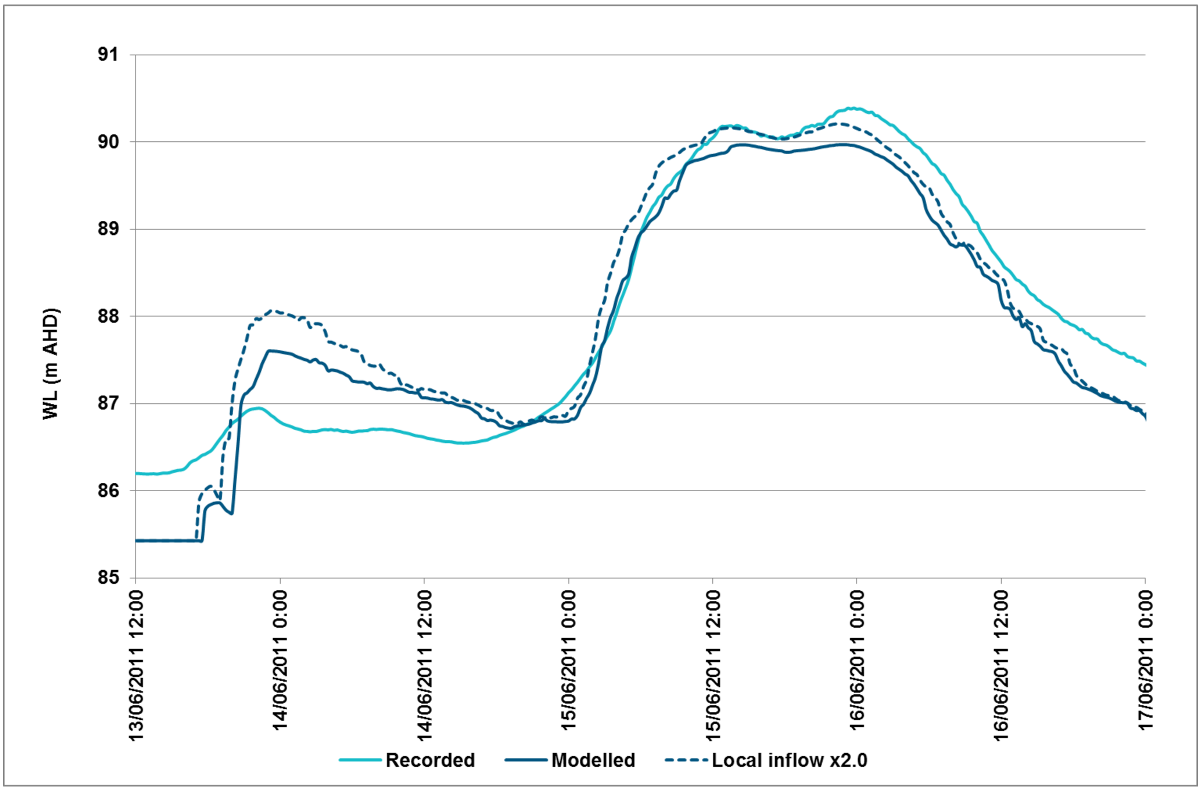
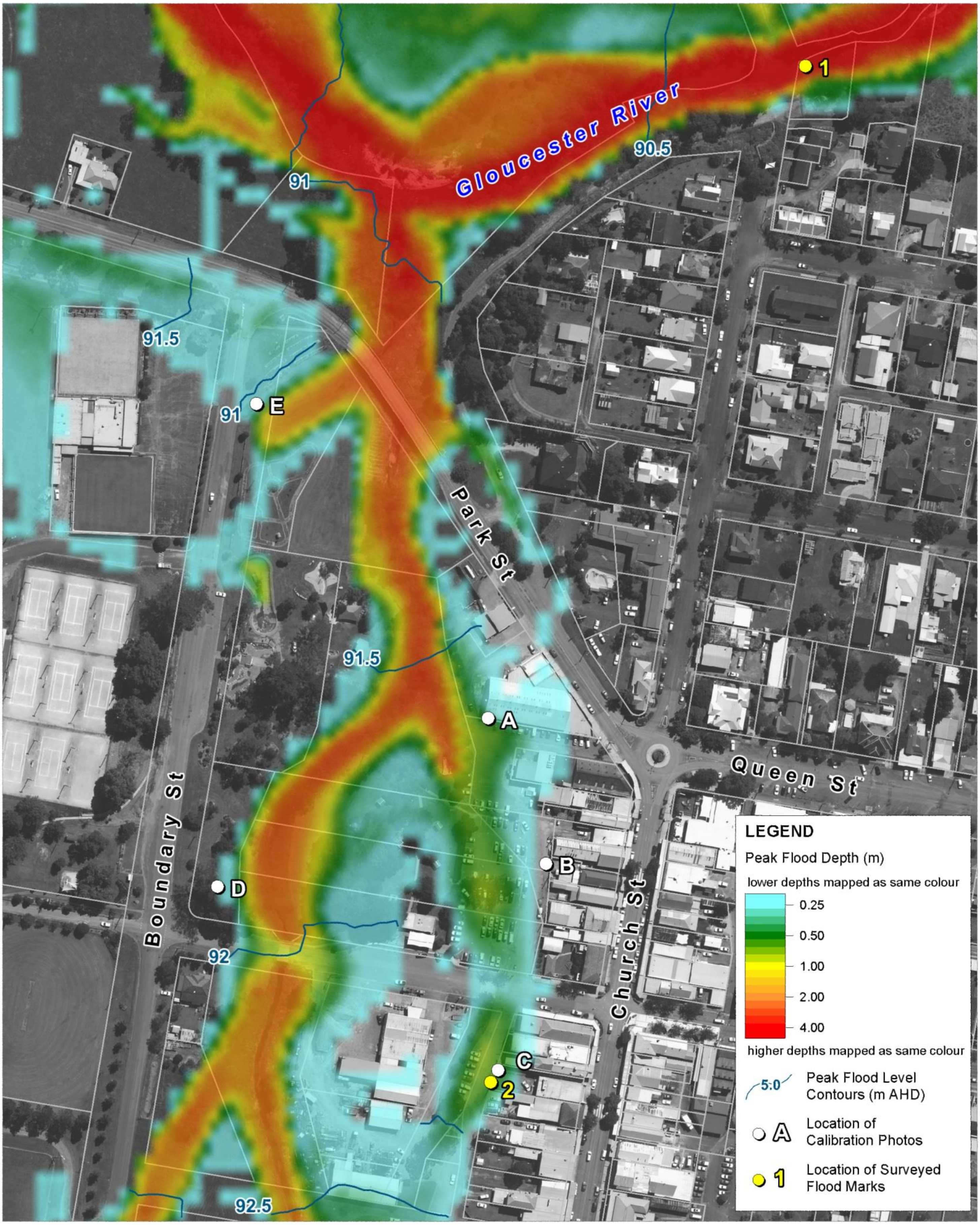


Figure 6-11 Comparison of Recorded and Modelled Water Levels at the Gloucester River at Gloucester Gauge for the June 2011 Event

A number of flood photographs were taken around The Billabong after the June 2011 event and were provided by Council. These depict flood debris marks and allow peak water levels through The Billabong to be estimated. Additional comments and approximate levels for this event were also provided by community members as a result of the Community Questionnaire. The location of calibration photos and survey marks are shown in Figure 6-12.

The June 2011 event was large enough to result in flood waters spilling out of the Billabong park channel across Billabong Lane. This did not occur in the initial model simulations. Comparison of Figure 6-9 and Figure 6-11 suggests that a larger amount of rainfall may have fallen between the Forbesdale gauge and Gloucester than that which has been modelled, as the peak flood levels are matched at Forbesdale but too low at Gloucester.



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June 2011 Model Calibration
The Billabong

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This pattern is not consistent for the other calibration events. For example the modelled peak flood level at Forbesdale is similar to the recorded for the 2013 event, but slightly higher than the recorded level at Gloucester. It is therefore most likely that the differences observed at Gloucester for the 2011 event are a function of the input rainfall data than a function of the hydrological model.

Given the uncertainty surrounding rainfall distribution and variation in intensity across the catchment due to limited continuous rainfall records, it is reasonable that considerably more rain fell along the lower Gloucester catchment than what was recorded at the Gloucester (Hiawatha) gauge.

The June 2011 calibration model was tested by increasing the flow inputs on the Gloucester River between Forbesdale and Gloucester, to give a better match to the recorded peak flood level at the Gloucester gauge. When this was undertaken the modelled flood conditions along The Billabong matched closely to those which were observed during the event. A comparison of these modelled levels against surveyed levels and those estimated from flood photos is shown in Table 6-4.

Table 6-4 Flood Marks for the June 2011 Event – The Billabong

		Flood Level (m AHD)	
ID	**Photo Location**	**Estimated**	**Modelled**
A	Turner Holden building	91.7	91.6
B	Butcher (39 Church St)*	91.8	-
C	Bakery (55 Church St)	91.8	91.9
D	Billabong Park (near Denison St)	91.9	92.0
E	Billabong Park (near Park St bridge)	91.0	91.2
ID	**Survey Location**	**Recorded**	**Modelled**
1	Gloucester River at Gloucester gauge	90.4	90.2
2	Rear fence of NPWS building (59 Church St)	91.8	92.0

It can be seen from Table 6-4 that there is a good match between the modelled peak flood levels and those estimated from the flood photographs. Three of the four observation points are within 0.1m, with the remaining point showing a difference of 0.2m. Both survey levels are within 0.2m of modelled levels. These results indicate that when a similar hydrograph to that recorded at Gloucester is modelled, a good match is achieved against calibration points through The Billabong.

The nature of flooding on the Avon River is considerably different to that experienced along the Barrington and Gloucester Rivers. The Avon River channel is narrow and meandering, sitting within a wider floodplain area. Stretches of the channel are perched above the floodplain.

There were multiple stream flow gauges in operation during the June 2011 flood event. The recorded vs. modelled peak water level hydrograph at the Avon River at DS Waukivory gauge (operated by NSW Office of Water) is presented in Figure 6-13. Generally, the modelled hydrograph displays a good match to the recorded peak water level at the gauge. The shape of the hydrograph up to 12:00pm on the 15th June is poorly represented. This can be attributed to uncertainty regarding spatial variation of initial rainfall over the catchment and is not a concern as the main peak of the flood wave is well represented.

The modelled peak water level is within 0.1m of the recorded level and the hydrograph shape is adequately replicated. Sensitivity testing indicated that the peak water level is not significantly influenced by model configuration. That is, increasing or decreasing channel roughness and altering rainfall distribution within the hydrological model had little effect on the peak water level modelled at the gauge. This is due to the nature of the Avon River channel, whereby once channel capacity is exceeded, flow spills onto the floodplain where a significant increase in volume of flow is required to drive the peak water higher, due to the flood storage available on the floodplain.

The in-channel roughness did affect the shape of the hydrograph during the flood wave recession. A roughness of 0.12 was adopted for the Avon River channel and was found to best achieve the recession of the recorded hydrograph, by replicating the drawn out peak water level toward the end of the June 2011 event.

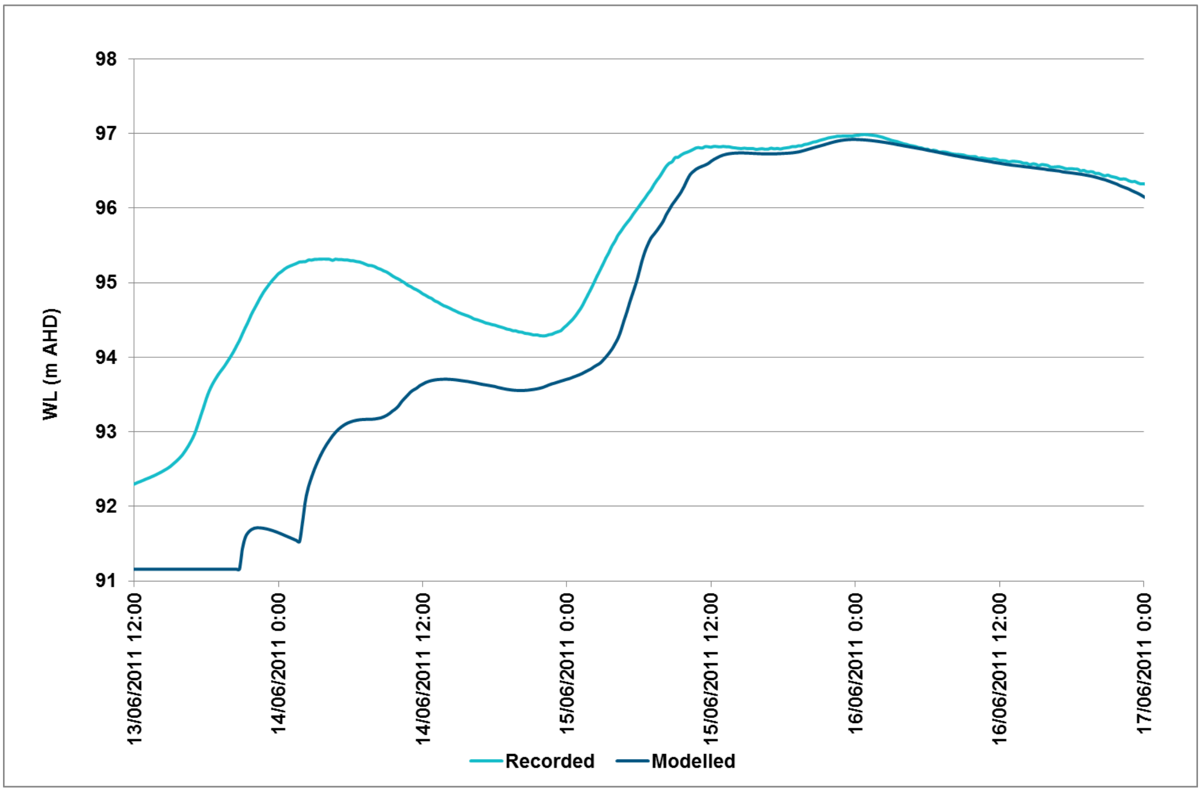
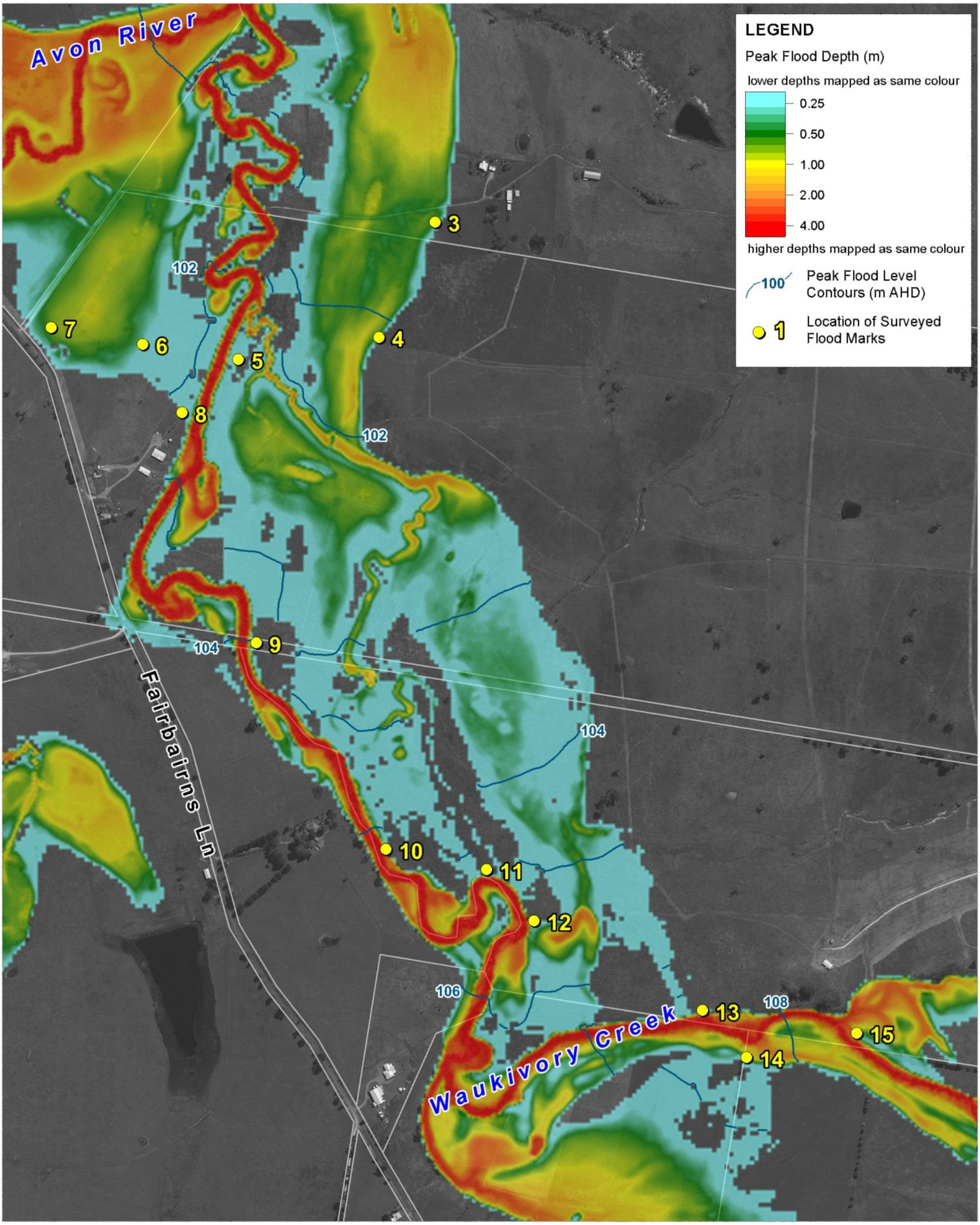


Figure 6-13 Comparison of Recorded and Modelled Water Levels at the Avon River at Downstream Waukivory Gauge for the June 2011 Event

A number of survey flood levels were recorded by GRL along Waukivory Creek for the June 2011 event. The location of these flood marks is shown in Figure 6-14. The recorded peak flood level is compared against modelled levels in Table 6-5.

The modelled flood level is consistently higher than the recorded level, evident in 12 out of 13 results. Almost half of the levels are within 0.2m. The largest differences between modelled and record water levels is noted at survey mark ID7 (+0.7m) and ID14 and I15 (+0.5m). The location of survey point ID7 is subject to inundation as a direct result of flooding along the Avon River.



Title:
June 2011 Model Calibration Waukivory Creek

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Previous calibration for the June 2011 event along this reach of Waukivory Creek produced similar discrepancies against these survey marks (Rocky Hill Coal Project – Surface Water Assessment, WRM 2013). This reach of the Waukivory Creek channel is slightly perched above the floodplain. The rainfall recorded during the June 2011 event is only relatively minor – around a 50% AEP and 20% AEP (based on 1987 IFDs) – with just enough runoff generated to overtop the creek.

For events of smaller magnitude, including the June 2011 event, local topographic controls such as natural surface elevations, road embankments and drainage lines will largely influence flood behaviour. Flood levels along the creek and within the floodplain will depend on the elevation of the creek bank and level at which overtopping occurs. LiDAR elevations are usually accurate within ±0.1m, however heavy vegetation lining the Waukivory creek channel could slightly compromise the accuracy of elevations along the creek banks.

In larger flood events, accurate definition the bank elevation is not as critical as the wider floodplain storage will drive flood levels and the influence of possible bank elevation differences in the order of 0.2m would be less significant.

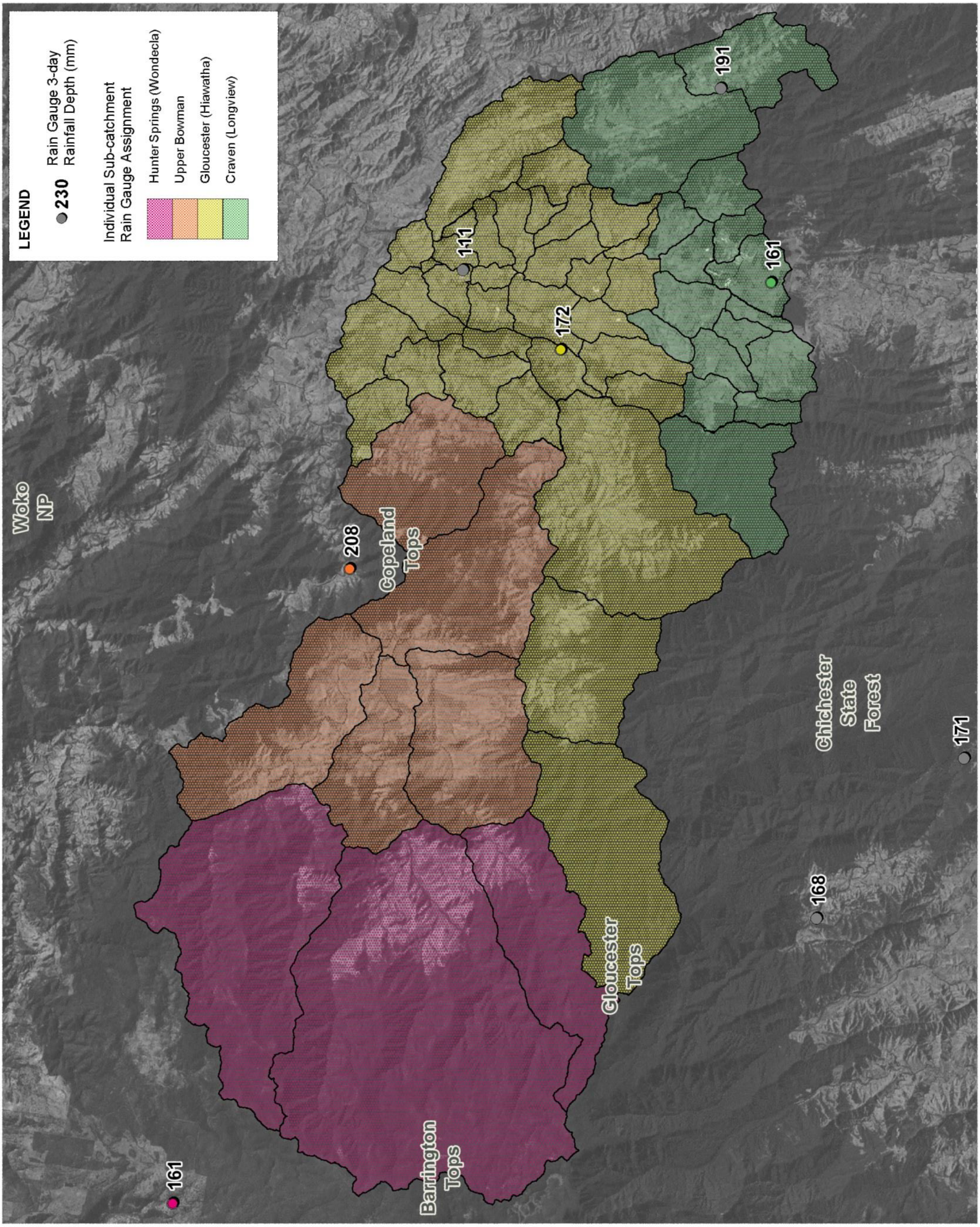
Table 6-5 Flood Marks for the June 2011 Event - Waukivory Creek

		Flood Level (m AHD)	
ID	Survey Location	Recorded	Modelled
3	Waukivory Creek (GRL Survey Peg 15)	100.0	100.4
4	Waukivory Creek (GRL Survey Peg 13)	100.9	101.0
5	Waukivory Creek (GRL Survey Peg 11)	102.1	102.4
6	Waukivory Creek (GRL Survey Peg 10)	100.8	101.1
7	Waukivory Creek (GRL Survey Peg 12)	100.4	101.1
8	Waukivory Creek (GRL Survey Peg 8)	102.7	102.8
9	Waukivory Creek (GRL Survey Peg 9)	104.2	104.0
10	Waukivory Creek (GRL Survey Peg 'Doug')	104.9	105.1
11	Waukivory Creek (GRL Survey Peg 7)	105.3	105.5
12	Waukivory Creek (GRL Survey Peg 5)	105.5	105.7
13	Waukivory Creek (GRL Survey Peg 3)	107.6	107.7
14	Waukivory Creek (GRL Survey Peg 4)	107.4	107.9
15	Waukivory Creek (GRL Survey Peg 1)	107.7	108.2

6.4 February 2013 Model Calibration

6.4.1 Rainfall Data

Four continuous rainfall gauges located within the vicinity of the study catchments recorded rainfall data for the February 2013 event. An additional two gauges in the catchment recorded daily totals. The location of the daily and continuous rainfall gauges is presented in Figure 6-15, with daily totals presented in Table 6-6.



Title:
February 2013 Rain Gauge Distribution and Recorded Rainfall

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Table 6-6 Daily Rainfall Records – February 2013 Event

Gauge Location	23rd Feb (mm)	24th Feb (mm)	25th Feb (mm)
Hunter Springs (Wondecla)	114	47	0
Upper Bowman	145	34	29
Gloucester Post Office	→	→	111*
Gloucester (Hiawatha)	107	34	31
Craven (Longview)	105	45	11
Waukivory	141	47	3

**Three day cumulative rainfall total.*

The daily rainfall distribution shows that the majority of the rain occurred on the 23rd, recording around 110mm across much of the catchment. However, a greater depth of rainfall occurred at both the Upper Bowman and Waukivory gauges.

The hourly rainfall hyetographs for the continuous gauges on the 22nd, 23rd and 24th February 2013 rainfall record are presented in Figure 6-16 and Figure 6-17.

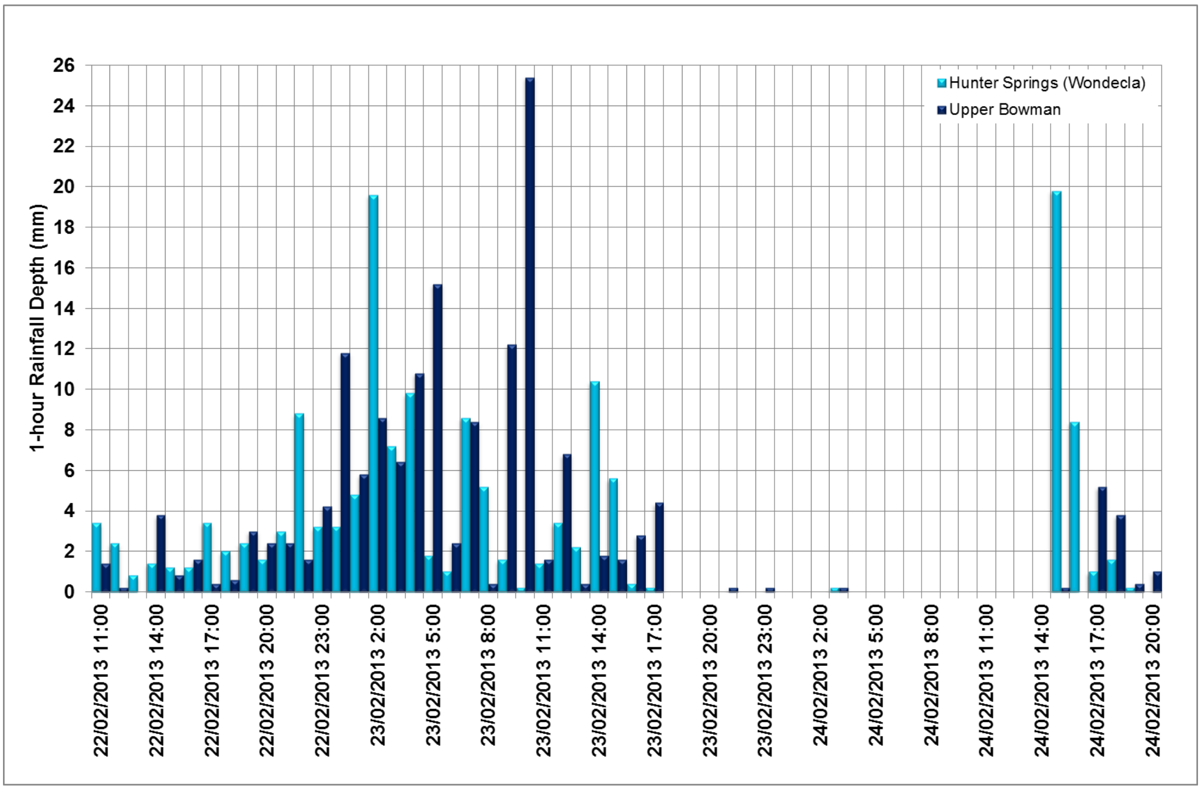


Figure 6-16 1-hour Rainfall Hyetograph for the February 2013 Calibration Event at the Hunter Springs (Wondecla) and Upper Bowman Gauges

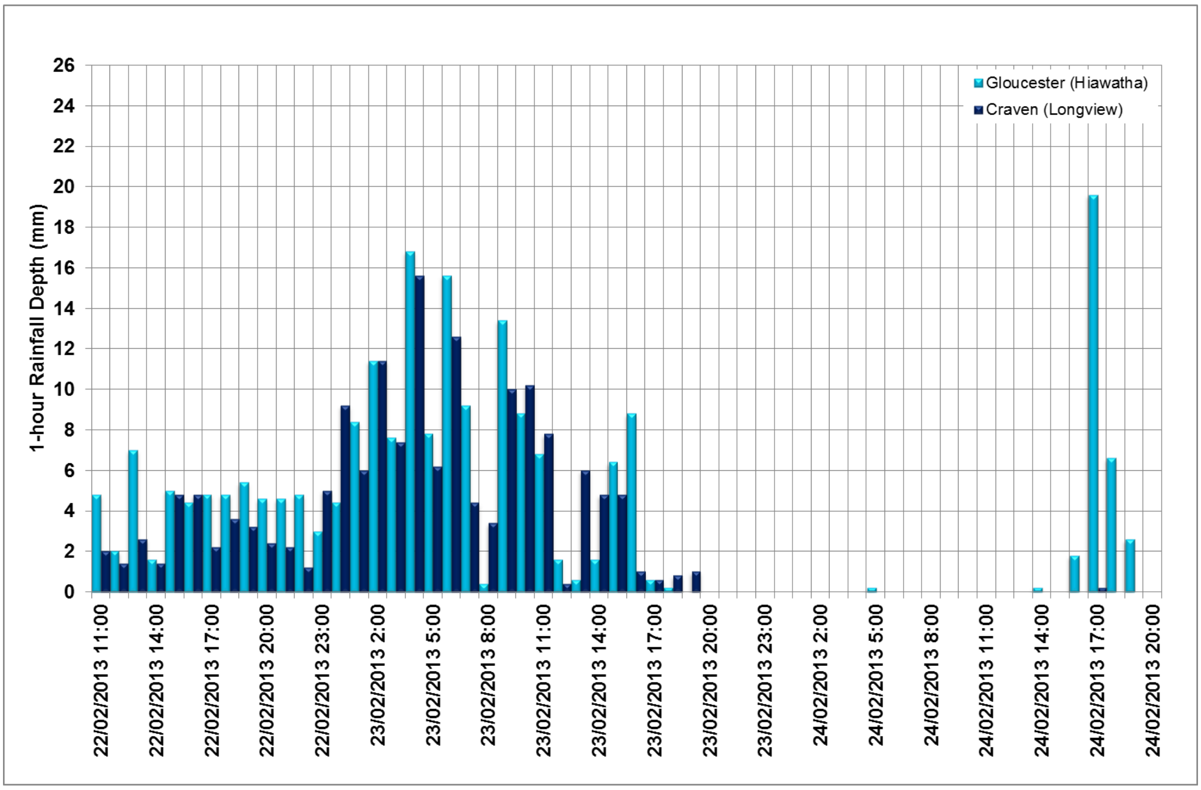


Figure 6-17 1-hour Rainfall Hyetograph for the February 2013 Calibration Event at the Gloucester (Hiawatha) and Craven (Longview) Gauges

Both Figure 6-16 and Figure 6-17 show that rain fell across the catchment from11:00am on the 22nd to 5:00pm on the 23rd of February. Variation in intensity was observed between the Hunter Springs (Wondecla) and the Upper Bowman gauges. Generally, 1-hour depths of rainfall recorded at Hunter Springs increased up to 2:00am on the 23rd, where a maximum intensity of around 20mm/hr was recorded. The records at the Upper Bowman gauge followed a similar pattern, but storm intensity peaked around 8 hours later with over 25mm/hr recorded at 10am on the 23rd.

Figure 6-17 shows that during this time period, both gauges located on the lower floodplain near Gloucester recorded similar rainfall hyetographs, where a maximum intensity of around 16mm was recorded at 4:00am on the 23rd. The rainfall hyetographs demonstrate the spatial variability in rainfall across the catchment evident during the February 2013 event.

The approach adopted to distribute temporal patterns to each sub-catchment was similar to that used for the June 2011 event, taking into account distance from the gauges and consistency of both elevation and terrain characteristics. However, initial model simulations resulted in too great a peak flow rate for the Gloucester River at Forbesdale. The upper two sub-catchments on the Gloucester River were therefore switched to the rainfall distribution recorded at the Gloucester (Hiawatha) gauge and the modelled peak flow rates were significantly improved. The adopted sub catchment allocation is presented is Figure 6-15.

A second intense peak of rainfall was recorded by the gauges at Hunter Springs (Wondecla) and Gloucester (Hiawatha) from 3:00-7:00pm on the 24th of February, around 24 hours after the main storm burst. Although this additional rainfall does not contribute to peak flood conditions within the catchment, it was included in the hydrological model for calibration purposes.

Comparison of recorded rainfall depth for various durations within the storm against design IFD curves derived for the catchment are shown in Figure 6-18 and Figure 6-19. Compared to June 2011 rainfall, the February 2013 event was larger at Gloucester but of smaller magnitude over the Barrington River catchment.

The gauges located on the Barrington Tops recorded rainfall intensities generally less than the 50% AEP level (1987 IFDs). That is, rainfall of this intensity is expected to occur more frequently than once every 2 years. The 2013 IFDs indicate that under revised estimates, the February 2013 event on the Barrington Tops is rarer than this, lying somewhere between a 50% AEP and 20% AEP magnitude. The 24h-36h period of rainfall recorded at the Gloucester (Hiawatha) gauge was equivalent to around a 20% AEP (1987 IFDs) or a 10% AEP (2013 IFDs).

6.4.2 Antecedent Conditions

Prior to the onset of rainfall of the February 2013 event average daily rainfall totals of 1mm, 3mm and 8mm were recorded across the catchment at 9am on the 20th, 21st and 22nd. An initial loss of 10mm was determined to be most representative of this condition and was adopted for the February 2013 calibration event.

6.4.3 Downstream Boundary Condition

No information was available to establish a flood level at the downstream boundary. However, the flood event is of too small a magnitude for the boundary condition to influence flood levels at Gloucester.

6.4.4 Adopted Model Parameters

The adopted model parameters for the February 2013 event, as shown in Table 6-7 were identical to those used in the June 2011 model calibration, with the exception of the initial loss parameter.

Table 6-7 February 2013 Adopted Model Parameters

Parameter	Value
Initial Loss (mm)	10
Continuing Loss (mm/hr)	2.5
PERN *Forested* *Cleared*	 0.12 0.06
Bx (storage routing parameter)	1.0
Manning's n (channel) *Barrington River and Gloucester River* *Avon River and Waukivory Creek*	 0.04 0.12
Manning's n (floodplain)	0.06

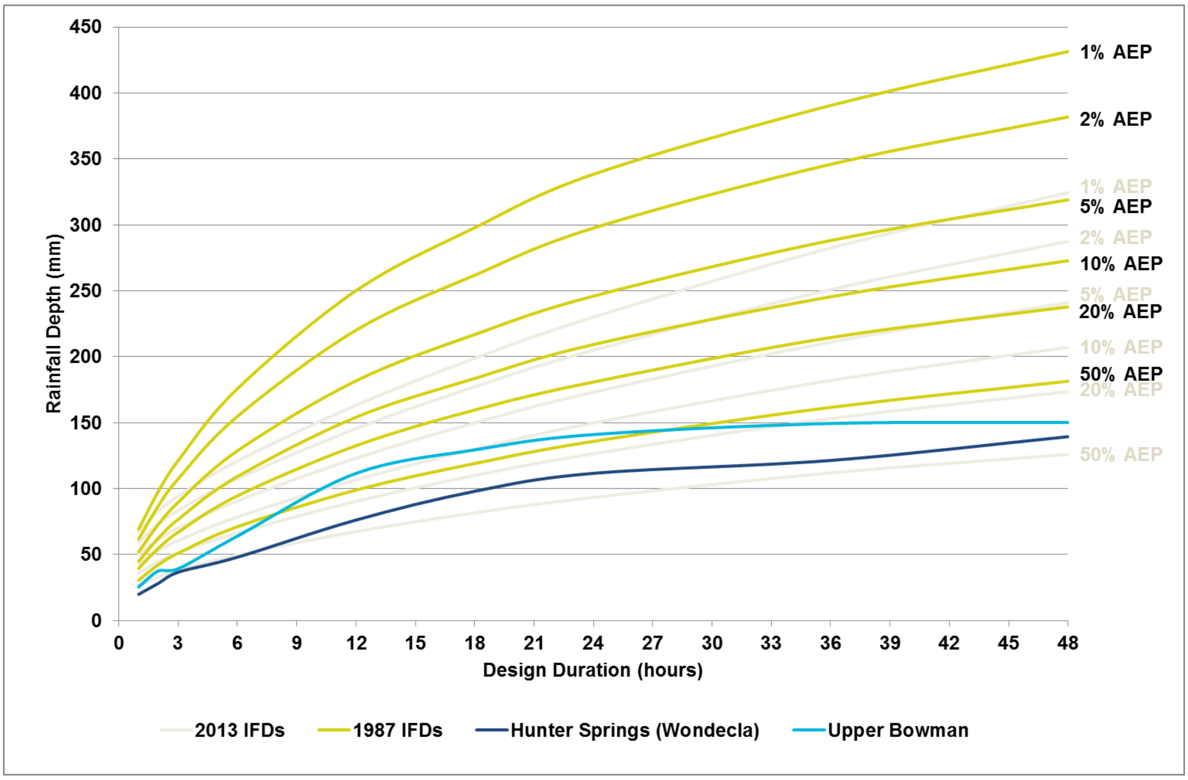


Figure 6-18 Comparison of Recorded February 2013 Rainfall at the Hunter Springs (Wondecla) and Upper Bowman Gauges with IFD Relationships

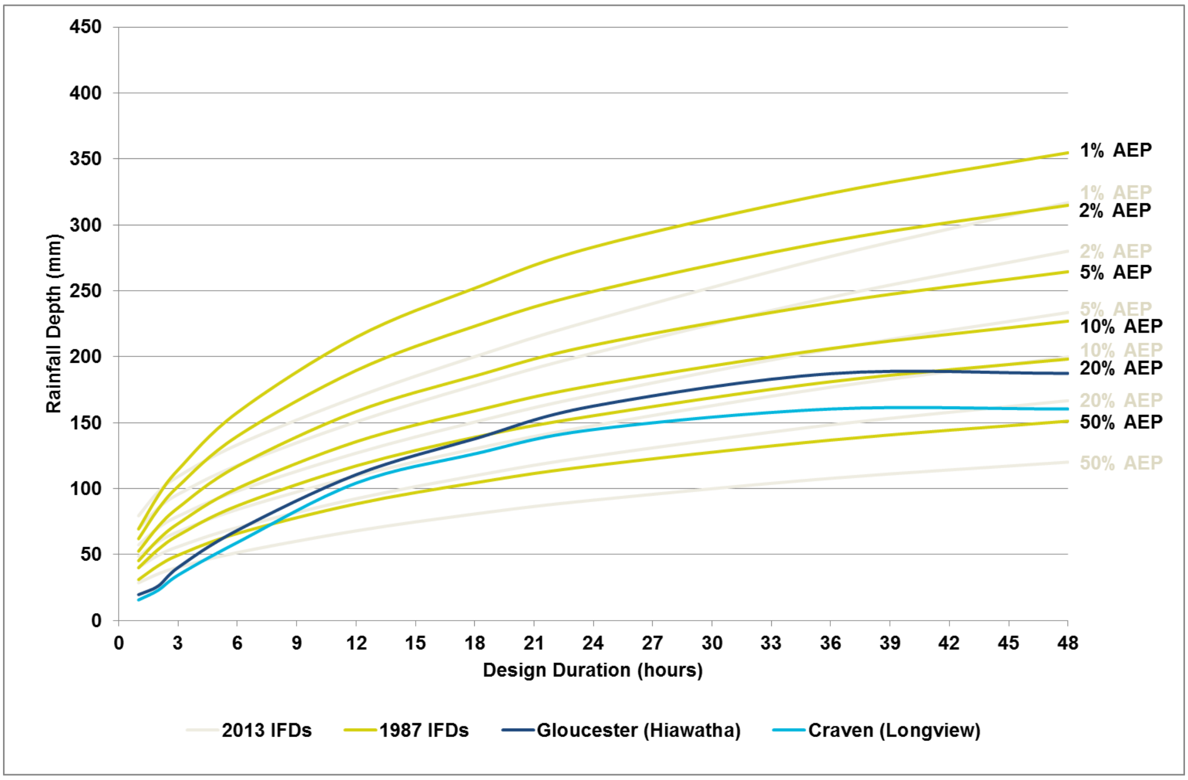


Figure 6-19 Comparison of Recorded February 2013 Rainfall at the Gloucester (Hiawatha) and Craven (Longview) Gauges with IFD Relationships

6.4.5 Observed and Simulated Flood Behaviour

The model calibration for the February 2013 event has again been undertaken using water level hydrographs recorded at various stream flow gauges across the catchment. Stream flow gauges were operational at both Forbesdale gauges, the Gloucester River at Gloucester and the Avon River at Downstream Waukivory.

The Barrington River at Relfs Road gauge did not record the event and so cannot be used to assess model calibration. In addition to the NSW Office of Water gauges, three of the four AGL-operated stream flow gauges on the upper Avon River recorded the February 2013 event.

The flow hydrographs were extracted from the hydrological model at the Forbesdale gauges and were input as inflow boundaries to the hydraulic model upstream of the gauging sites. The modelled peak flow rates at the two Forbesdale gauges are presented in Table 6-8.

Figure 6-20 and Figure 6-21 show the modelled water levels at the Barrington River at Forbesdale and the Gloucester River at Forbesdale gauges against the recorded data for the February 2013 event. The model accurately replicates the peak flood levels within 0.1m of the recorded level. The overall shape of the flood hydrograph is also well represented, albeit with a slight underestimation through the recession.

The timing of the peak water level on the Barrington River at Forbesdale gauge is modelled approximately 2.5 hrs after it was recorded, and is likely due to uncertainties regarding the temporal pattern of rainfall during the event. With reference to Figure 6-18, the period of most intense rainfall recorded at the Hunter Springs (Wondecla) and Upper Bowman rainfall gauges occurs 9 hours apart. Although it could be assumed that more intense rainfall fell earlier i.e. the Hunters Springs temporal pattern may be more representative of rainfall over the Barrington River catchment, the coarse distribution of rainfall across the sub-catchments is considered appropriate in the absence of additional rainfall records.

The timing of both the first and second peaks recorded at the Gloucester River at Forbesdale gauge is well represented in the modelled hydrograph. The initial response of the flood wave is modelled to occur around an hour before it was recorded, resulting in an overestimation of the volume of water at this gauge and can be seen in Figure 6-21. The large degree of spatial variation in rainfall intensity apparent during the February 2013 event was detailed in Section 6.4.1. It is likely that during this event, the initial rainfall that fell on the upper Gloucester River catchment was perhaps somewhere between that recorded on the Barrington Tops (Figure 6-16) and on the lower floodplain near Gloucester (Figure 6-17).

The recorded vs. modelled peak flow at the Gloucester River at Gloucester gauge is presented in Figure 6-22. The overestimation of initial flow volume that was observed at Forbesdale has intensified travelling downstream to this location and can again be further attributed to the uncertainty regarding rainfall distribution during this event. The modelled peak water level is 0.2m higher than the recorded level at the Gloucester gauge. Further calibration levels and flood marks are not available for this event.

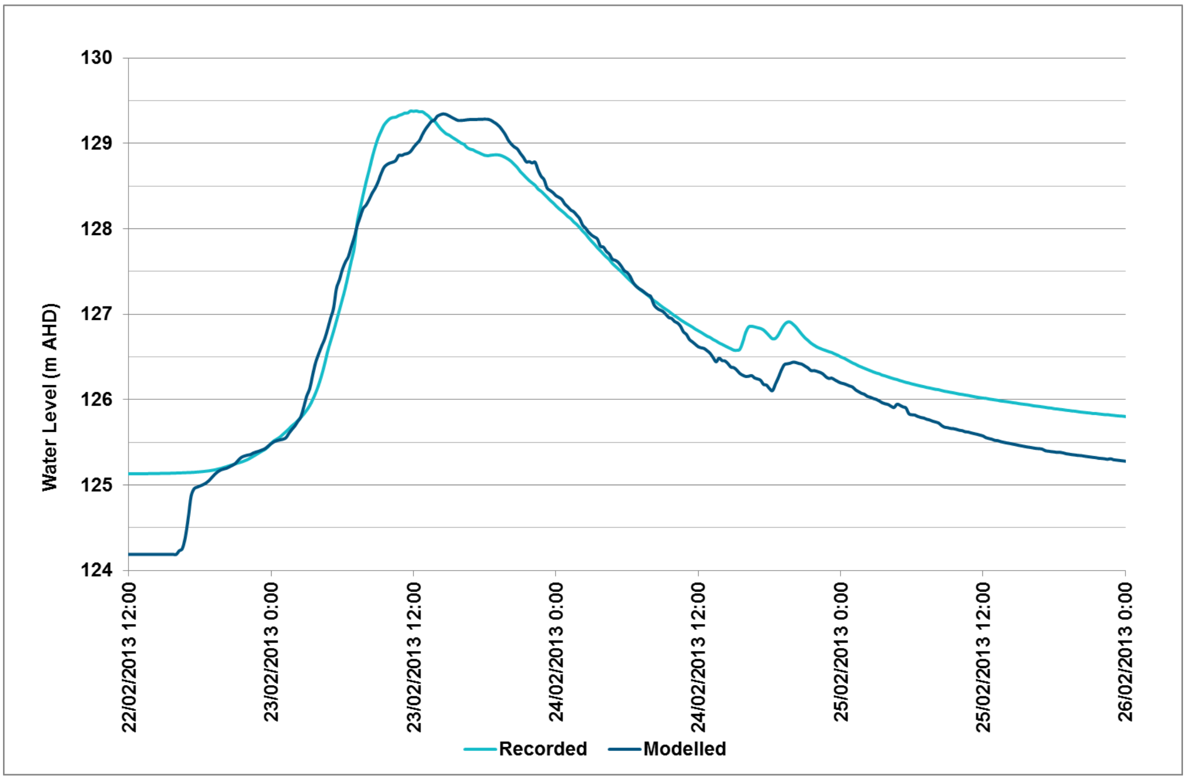


Figure 6-20 Comparison of Recorded and Modelled Water Levels at the Barrington River at Forbesdale Gauge for the February 2013 Event

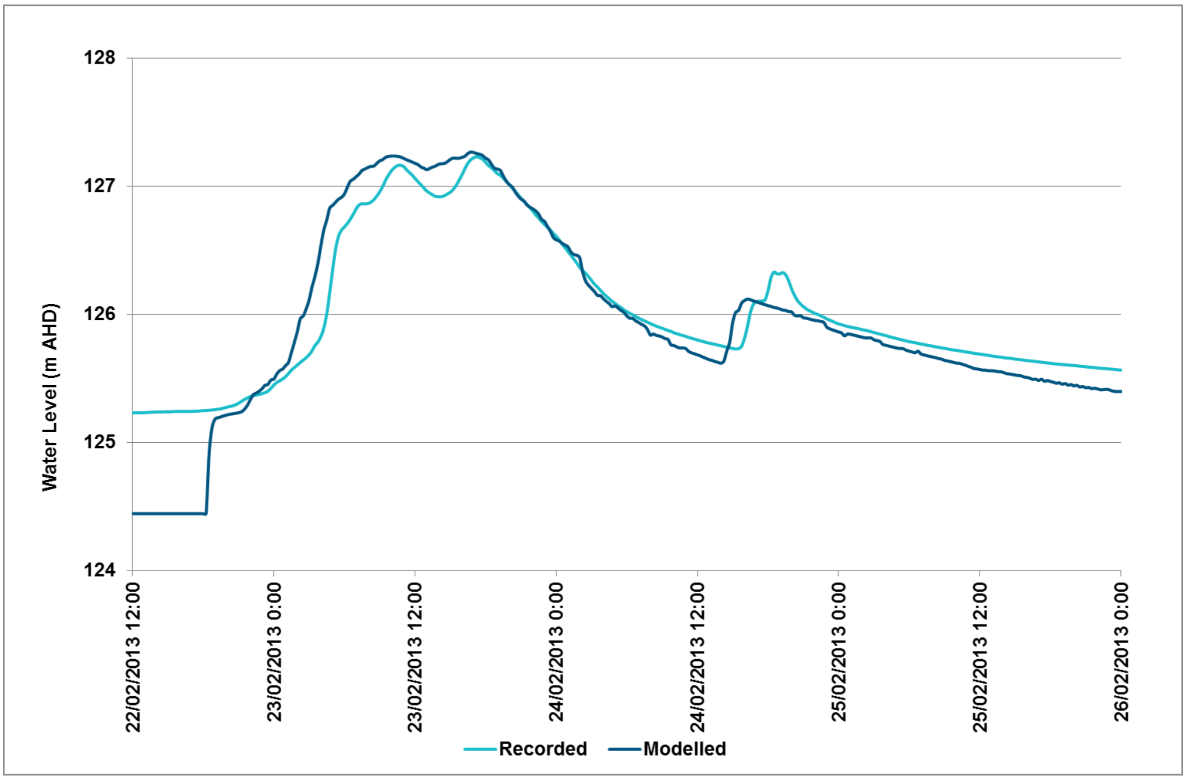


Figure 6-21 Comparison of Recorded and Modelled Water Levels at the Gloucester River at Forbesdale Gauge for the February 2013 Event

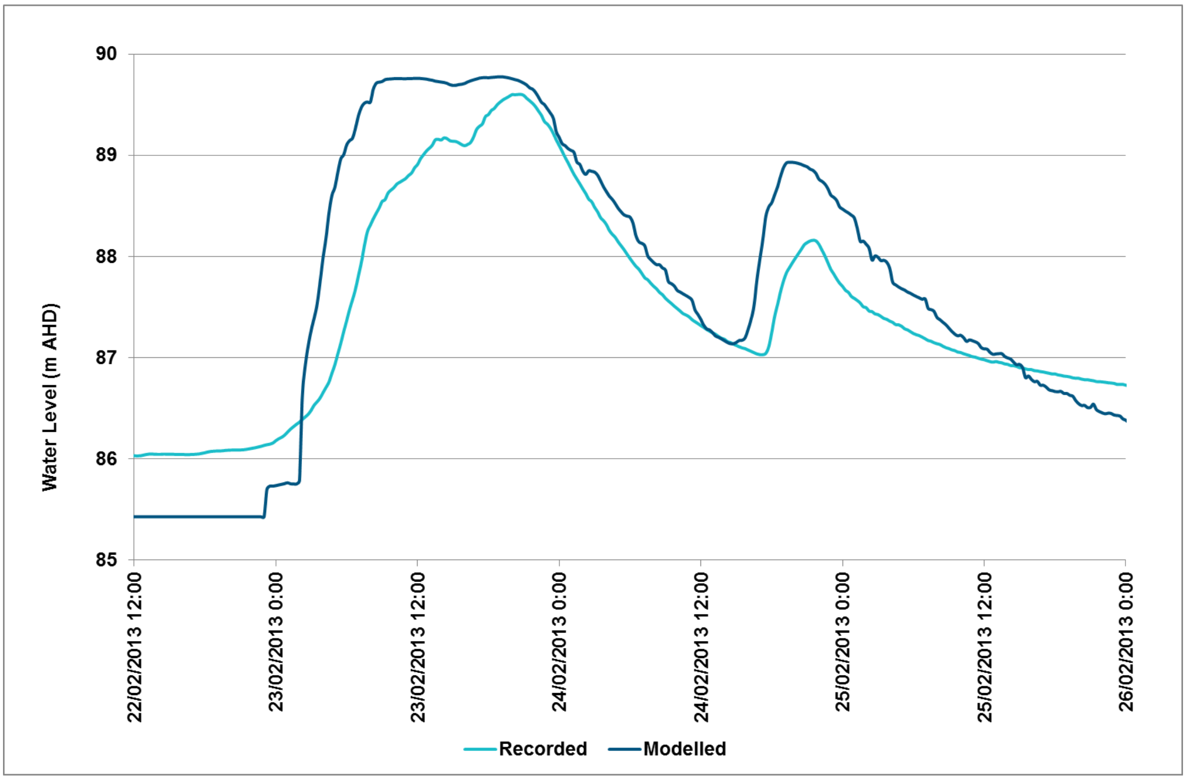


Figure 6-22 Comparison of Recorded and Modelled Water Levels at the Gloucester River at Gloucester for the February 2013 Event

The water levels recorded and modelled at the Avon River at Downstream Waukivory stream flow gauge is shown in Figure 6-23. A reasonable match is achieved in the calibration of the shape and timing of the water level hydrograph. The modelled peak water level is approximately 0.2m higher than the recorded peak at 96.8m AHD.

Table 6-8 Modelled Peak Flow Rates at the Forbesdale Gauges for the February 2013 Event

Gauge Location	Peak Flow Rate (m^3/s)
Barrington River at Forbesdale	700
Gloucester River at Forbesdale	185

6.5 March 1978 Model Verification

For the March 1978 event it was not possible to reproduce the observed flow conditions at the Forbesdale gauges from the available rainfall data. Therefore the approach for using the 1978 event was to input the observed flows at the Forbesdale gauges and assess the TUFLOW model performance at Gloucester.

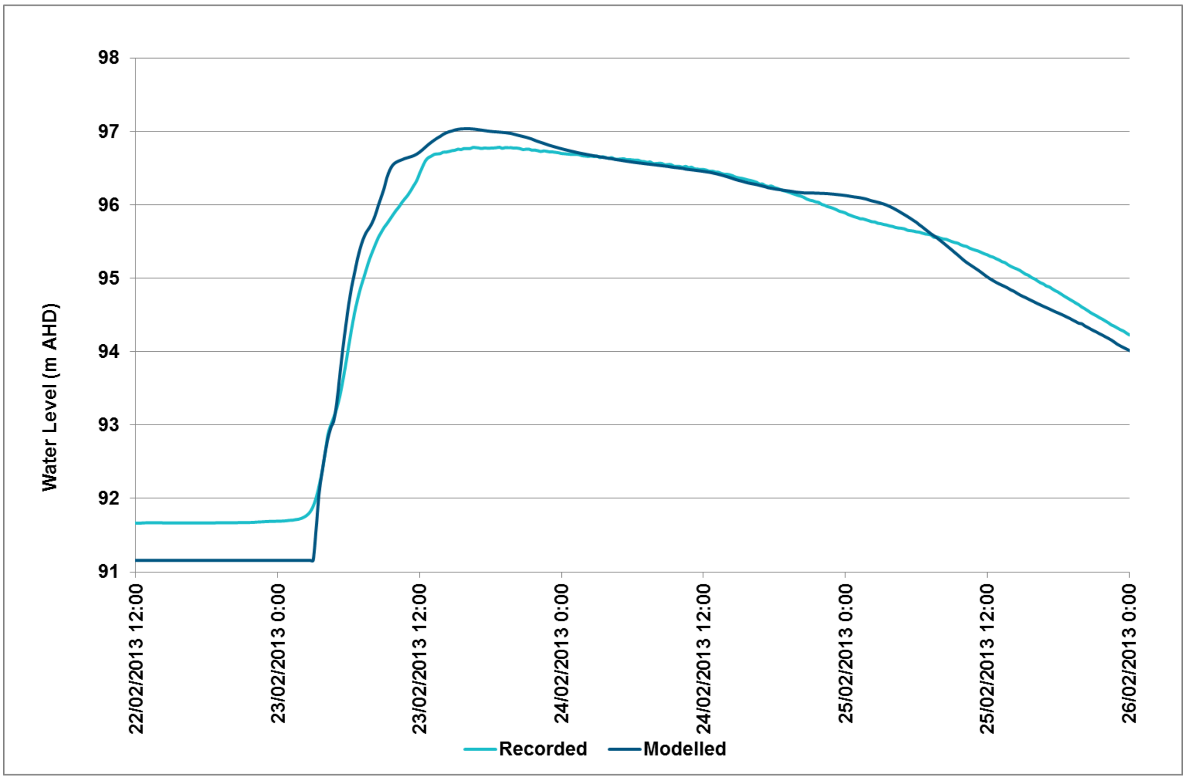


Figure 6-23 Comparison of Recorded and Modelled Water Levels at the Avon River at Downstream Waukivory Gauge for the February 2013 Event

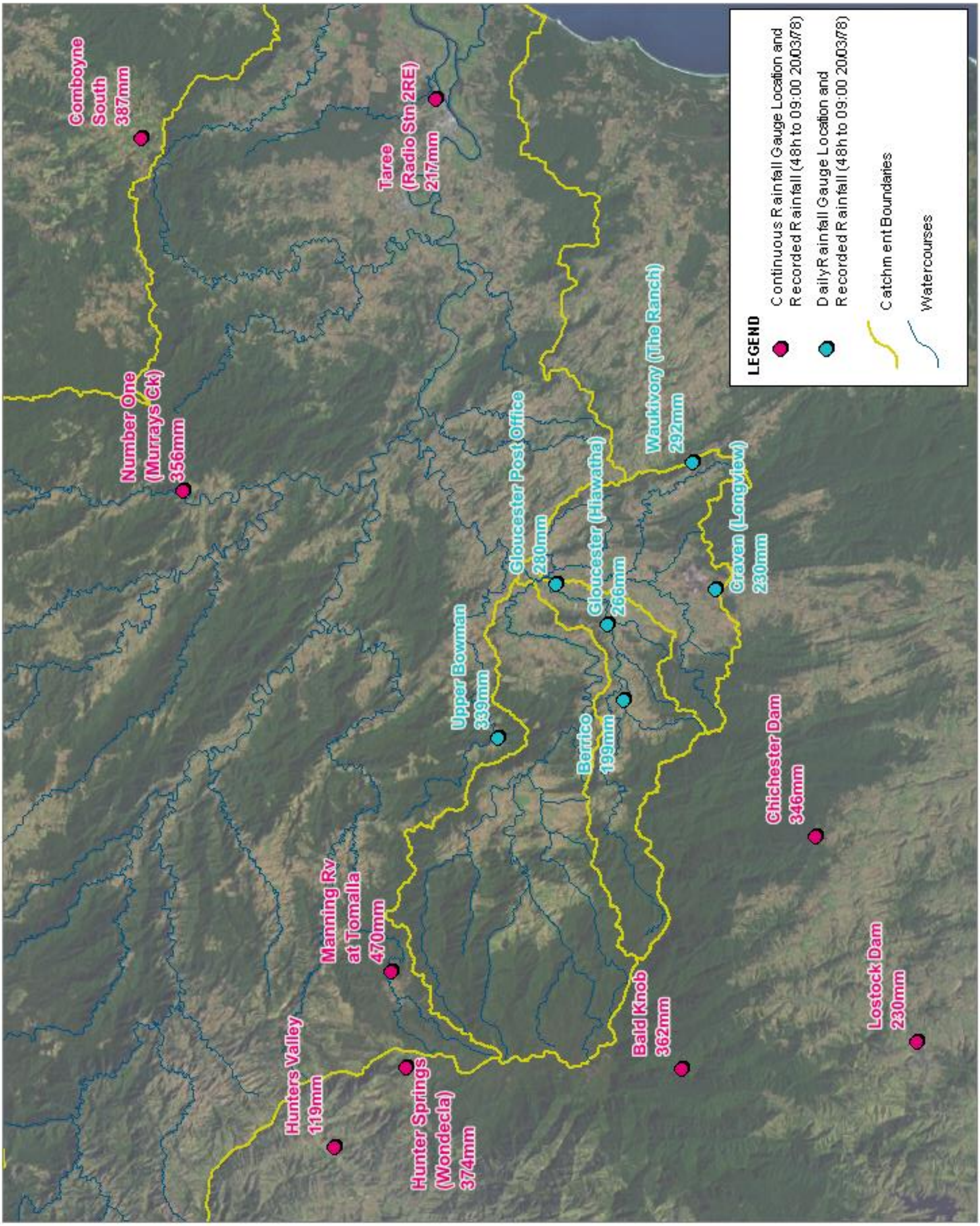
6.5.1 Rainfall Data

Flooding within Gloucester in March 1978 was driven by rainfall on 19th and 20th. There are a number of continuous rainfall gauges situated around the study catchments, but none within the catchments. There are a further six daily rainfall gauges situated within or adjacent to the study catchments, as presented on Figure 6-24.

The two closest continuous gauges are those at Hunter Springs (Wondecla) and the Manning River at Tomalla. These are situated on top of the Barrington plateau and may be representative of rainfall conditions in the high elevation areas.

The other close continuous gauges are less likely to be representative of rainfall conditions within the study catchments. Those at Bald Knob and Chichester Dam are situated within the southern valleys of the Tops and will experience different weather patterns to the east-facing valleys. Both gauges recorded large amounts of rainfall on 18th March, which did not occur at the other gauge locations.

The gauge at Hunters Valley is situated on the western slopes of the Barrington Tops and therefore sits within a rain shadow for storms arriving from the east. It recorded less rainfall than the other gauges. Gauges further afield are also less likely to be representative, given their distance from the study catchments.



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March 1978 Rain Gauge Distribution

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The hourly rainfall hyetographs for the two continuous gauges closest to the study catchments for the 19th and 20th March 1978 rainfall record are presented in Figure 6-25. Both exhibit a similar pattern of rainfall but with the Manning River at Tomalla gauge recording more intense rainfall. The more intense rainfall occurs across two distinct blocks – the first falling across much of 19th from around 04:00 to 19:00 and the second across the morning of 20th from around 00:00 to 11:00. The rainfall is more intense within the first block, particularly the last two hours in which almost 100mm of rainfall is recorded at Hunter Springs (Wondecla).

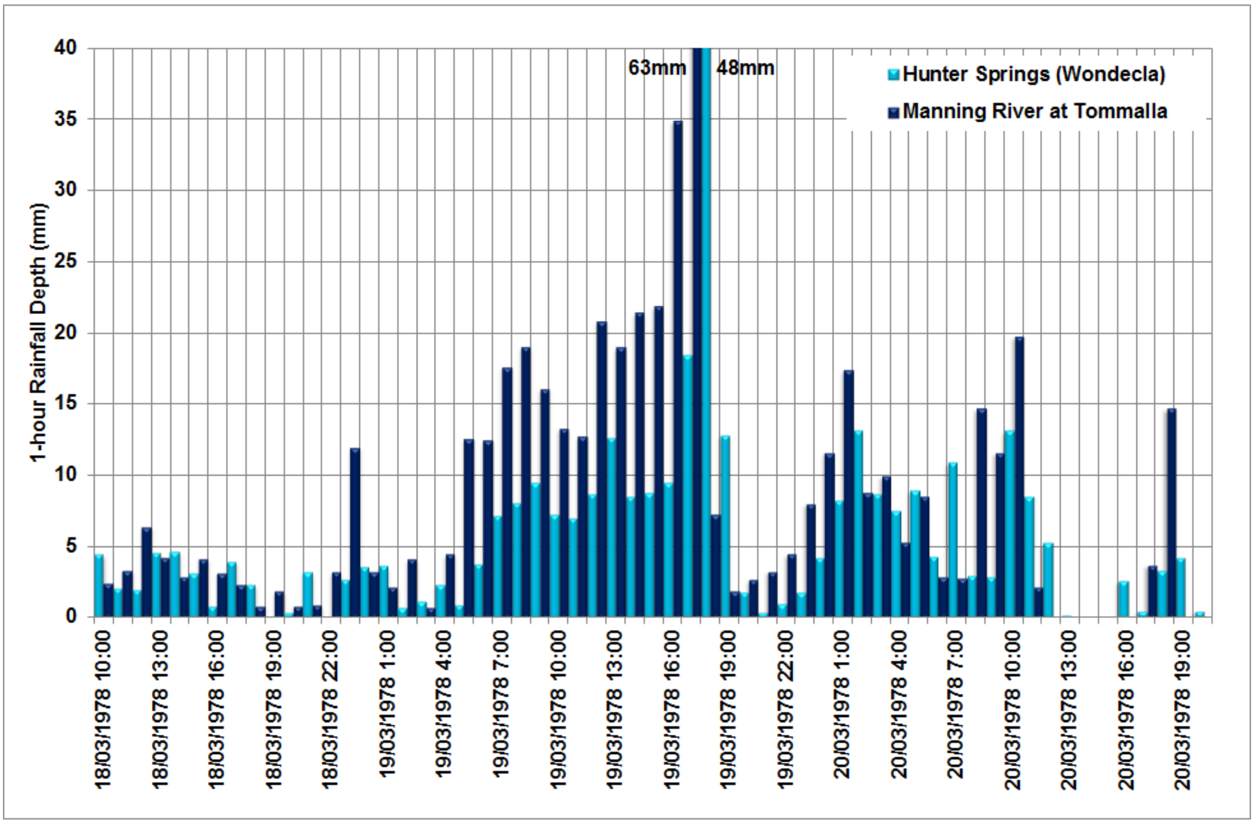


Figure 6-25 1-hour Rainfall Hyetograph for the March 1978 Event at the Hunter Springs (Wondecla) and Manning River at Tomalla Rain Gauges

When the rainfall record from these gauges was utilised in the hydrologic model it produced a strong initial flood peak from the first block of intense rainfall, which was sustained within the recession by the second block of rainfall.

The stream gauge records show two distinct peaks relating to the two blocks of intense rainfall, suggesting that a rainfall pattern of a more similar intensity within each block may have been more representative of the actual rainfall conditions across the catchments.

The previous flood study had achieved a reasonably representative response from the hydrological model, but this did not use the rainfall record at Hunter Springs (Wondecla) or the Manning River at Tomalla. Instead the Hunters Valley and Taree gauges were used, neither of which is expected to be representative of the study catchments. The corresponding hourly rainfall hyetographs for these two gauges are presented in Figure 6-26. It shows that the Hunters Valley gauge did not receive much rainfall during the first block of intense rainfall and the Taree record has a more definitive gap between the two blocks.

The rainfall input for the March 1978 event in the previous study produced a rainfall distribution for the study catchments as a composite of the Hunters Valley and Taree gauge records, averaging the two. Figure 6-26 shows that this composite rainfall distribution produces two rainfall blocks of a more similar intensity and has a larger gap between the two than do the records presented in Figure 6-25. Although this approach produces a rainfall pattern similar to that required to reproduce the catchment response in the hydrological model, it is difficult to justify given the distance of the gauges from the study catchments, when closer gauges are available. The March 1978 event was therefore not used to assess the performance of the hydrological model, but instead the performance of the hydraulic model only.

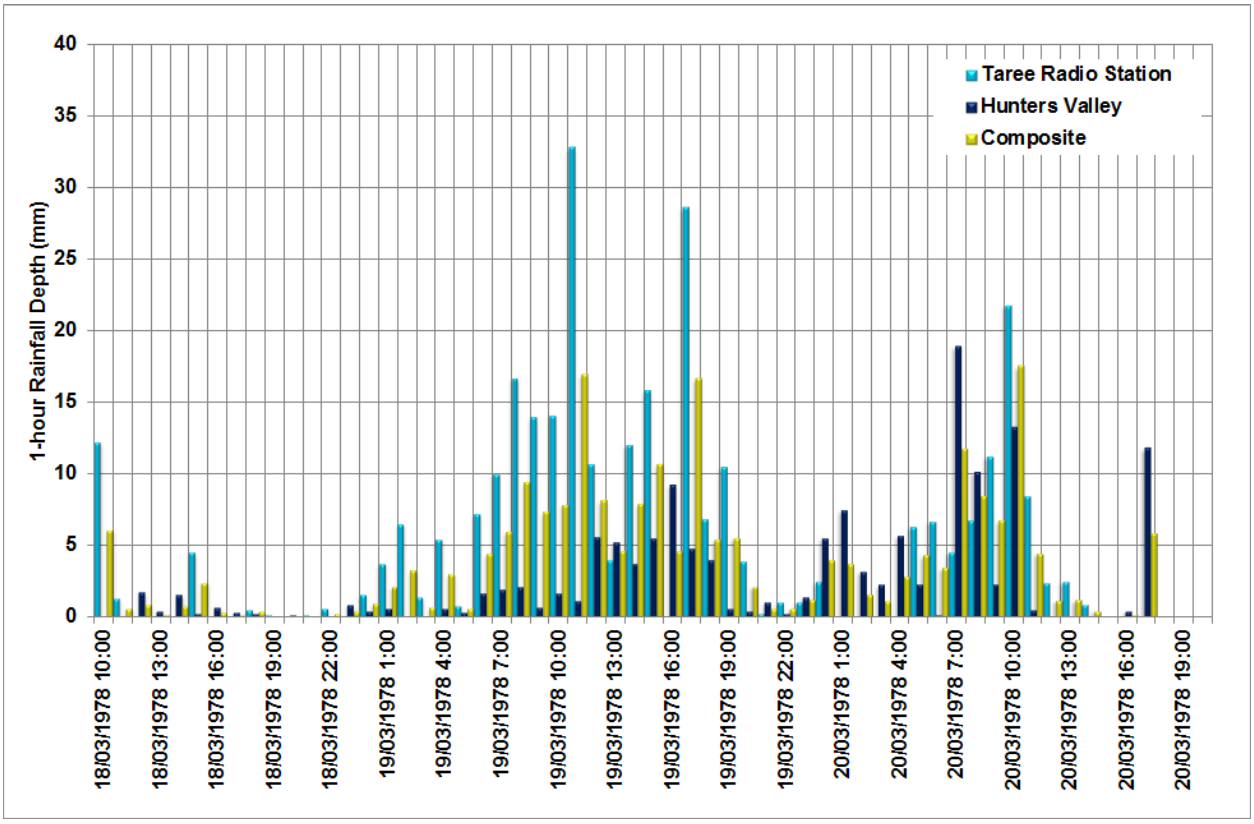


Figure 6-26 1-hour Rainfall Hyetograph for the March 1978 Event at the Hunters Valley and Taree Radio Station Rain Gauges

To gain an appreciation of the relative intensity of the March 1978 event, the recorded rainfall depths for various storm durations is compared with the design IFD data for the upper Barrington River catchment as shown in Figure 6-27. It shows that the magnitude of the event rainfall is reasonably consistent across the range of event durations. When compared to the 1987 IFDs the Hunter Springs (Wondecla) rainfall is close to a 5% AEP magnitude, with the rainfall at the Manning River at Tomalla representing around a 0.5% AEP magnitude. When comparing the records to the 2013 IFDs the magnitudes increase to around the 1% AEP and in excess of a 0.1% AEP respectively.

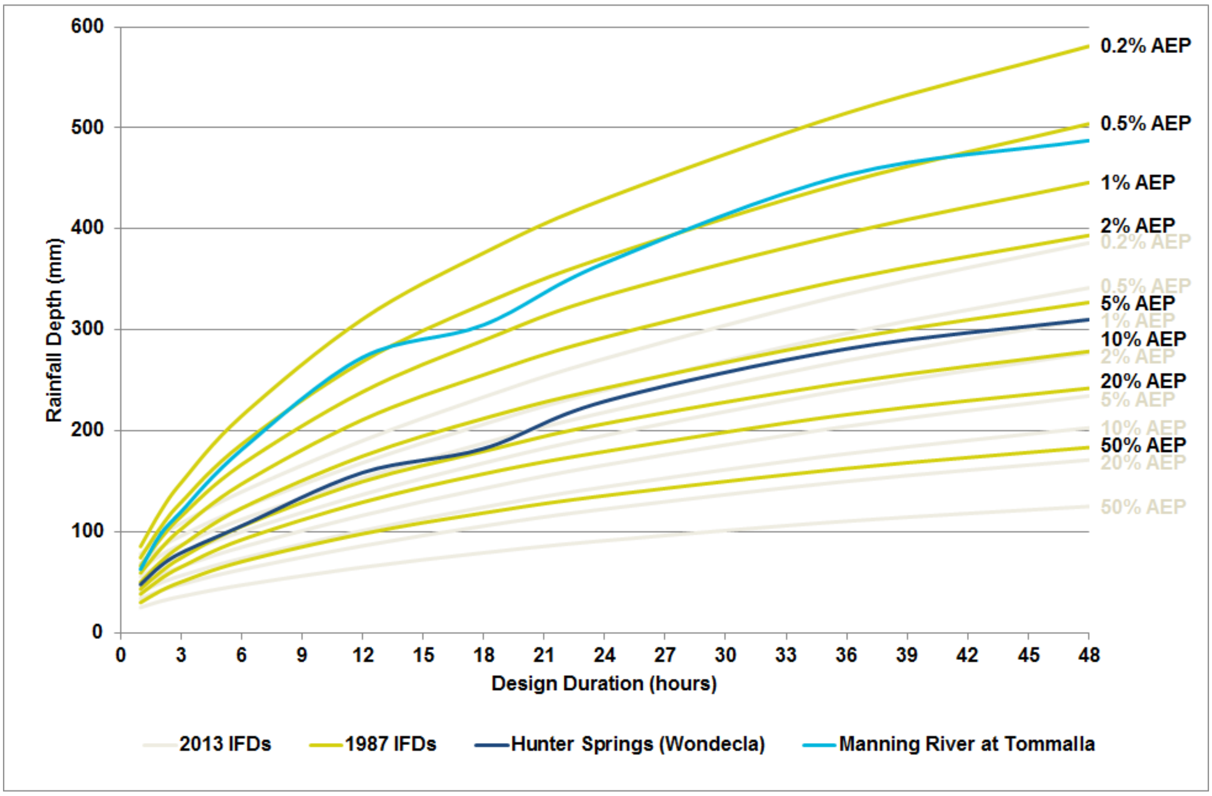


Figure 6-27 Comparison of Recorded March 1978 Rainfall at the Hunter Springs (Wondecla) and Manning River at Tomalla Gauges with IFD Relationships

6.5.2 Model Inflows

Due to the lack of representative temporal rainfall pattern for the study catchments, the model inflows for the Gloucester and Barrington Rivers were derived from the Forbesdale gauge records, rather than from the hydrological model outputs. The modelled rating curves presented in Figure 6-1 and Figure 6-2 were used to derive model inflow hydrographs from the water level records at the gauging stations and are presented in Figure 6-28.

Inflows on the Gloucester and Barrington Rivers between the Forbesdale gauges and the confluence have been derived from scaling of the Forbesdale hydrographs. The Gloucester inflow has been scaled to provide the required flow rate through Gloucester town.

For the Avon River the hydrological model was used to derive inflows for the hydraulic model. This adopted the temporal pattern from the Chichester Dam gauge, scaled to match the recorded daily rainfall totals from the gauges within the catchment.

6.5.3 Downstream Boundary Condition

An appropriate flood level at the downstream boundary was derived from surveyed flood marks along the Gloucester River. A level of 85.6m AHD was interpolated from observed flood levels upstream and downstream of the model boundary and applied as a fixed water level for the model simulation.

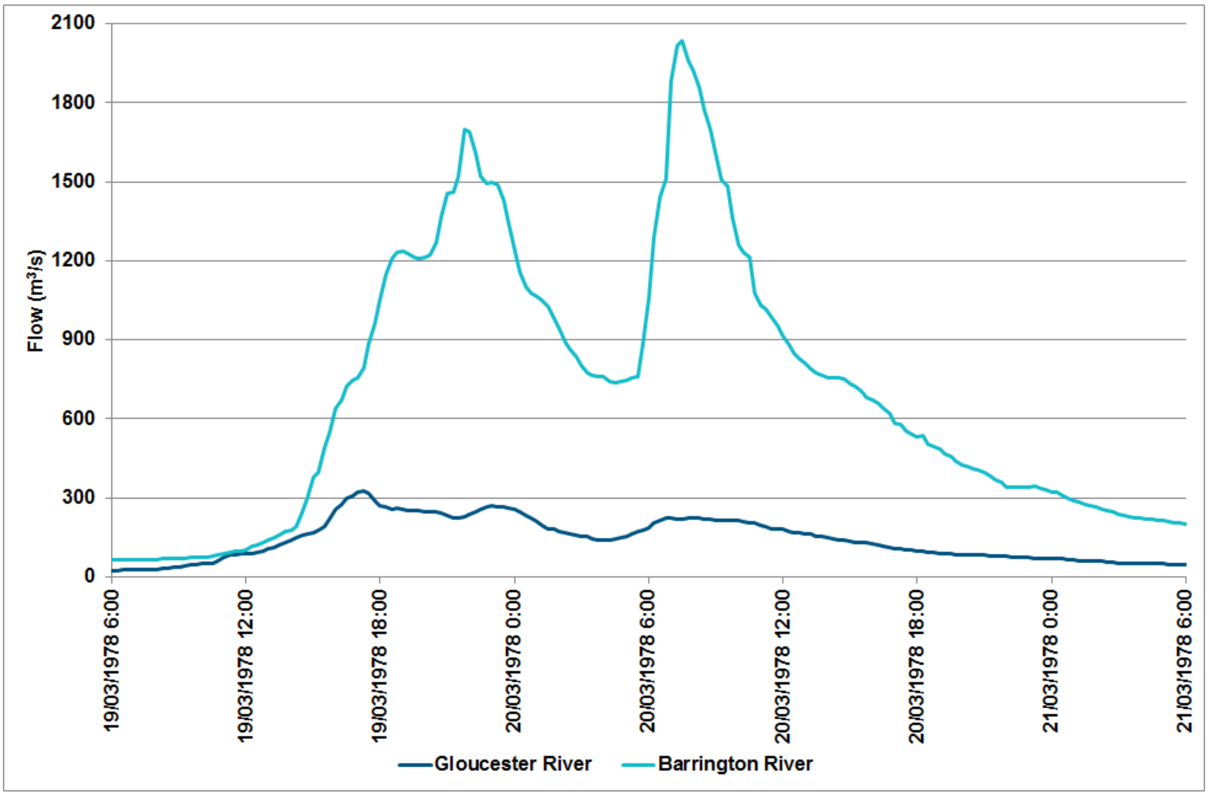


Figure 6-28 Model Inflow Hydrographs for the March 1978 Event

6.5.4 Observed and Simulated Flood Behaviour

The principal record available from which to assess the performance of the hydraulic model in simulating the March 1978 event is the recorded flood heights at the Gloucester (Lehmans Flat Bridge) gauge. The SES recorded periodic flood heights from the gauge board, which have been converted to AHD levels and presented in Figure 6-29.

There is some uncertainty regarding the times at which the levels were recorded at, as those reported in the previous study were incorrect. This was confirmed through local enquiries that indicated the timings of the two flood peaks were similar to those which were modelled. This is to be expected given that the recorded data at Forbesdale was used as the model inflow and the travel time from there to Gloucester is only around two hours.

The general shape of the modelled hydrograph at Gloucester is similar to that which was observed during the event, although there is some difference between the timings of the two peaks. This may be a function of the actual rainfall that fell within the catchment of the Gloucester River downstream of Forbesdale, compared to the flows that have been input to the model.

The 1978 event also represents around a 2% AEP to 1% AEP design condition in the Avon and Barrington Rivers. Events of this magnitude would have a significant impact on the flood levels at the Gloucester gauge (as presented in Section 6). As actual rainfall and flows for the Avon River during the 1978 event are unknown there is much uncertainty regarding the modelled conditions. Differences in timing and magnitude of the Avon River flow hydrograph would directly influence the shape and peak levels of the modelled hydrograph presented in Figure 6-29.

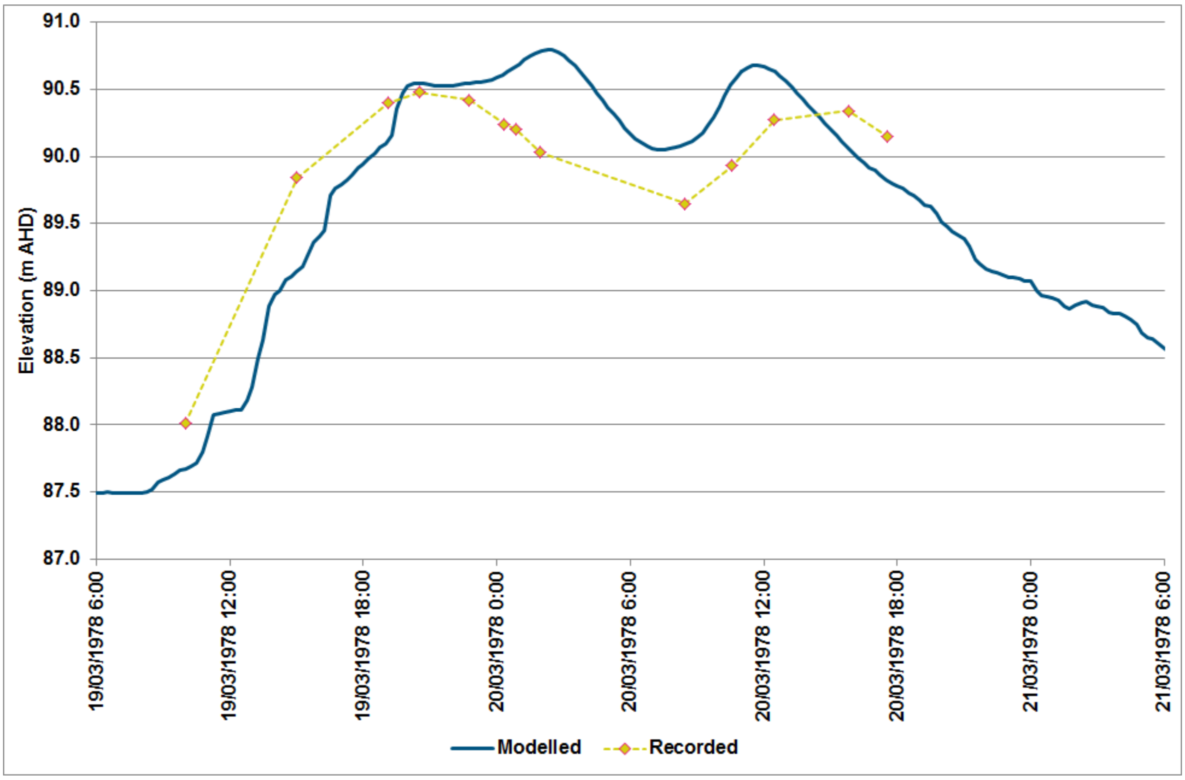


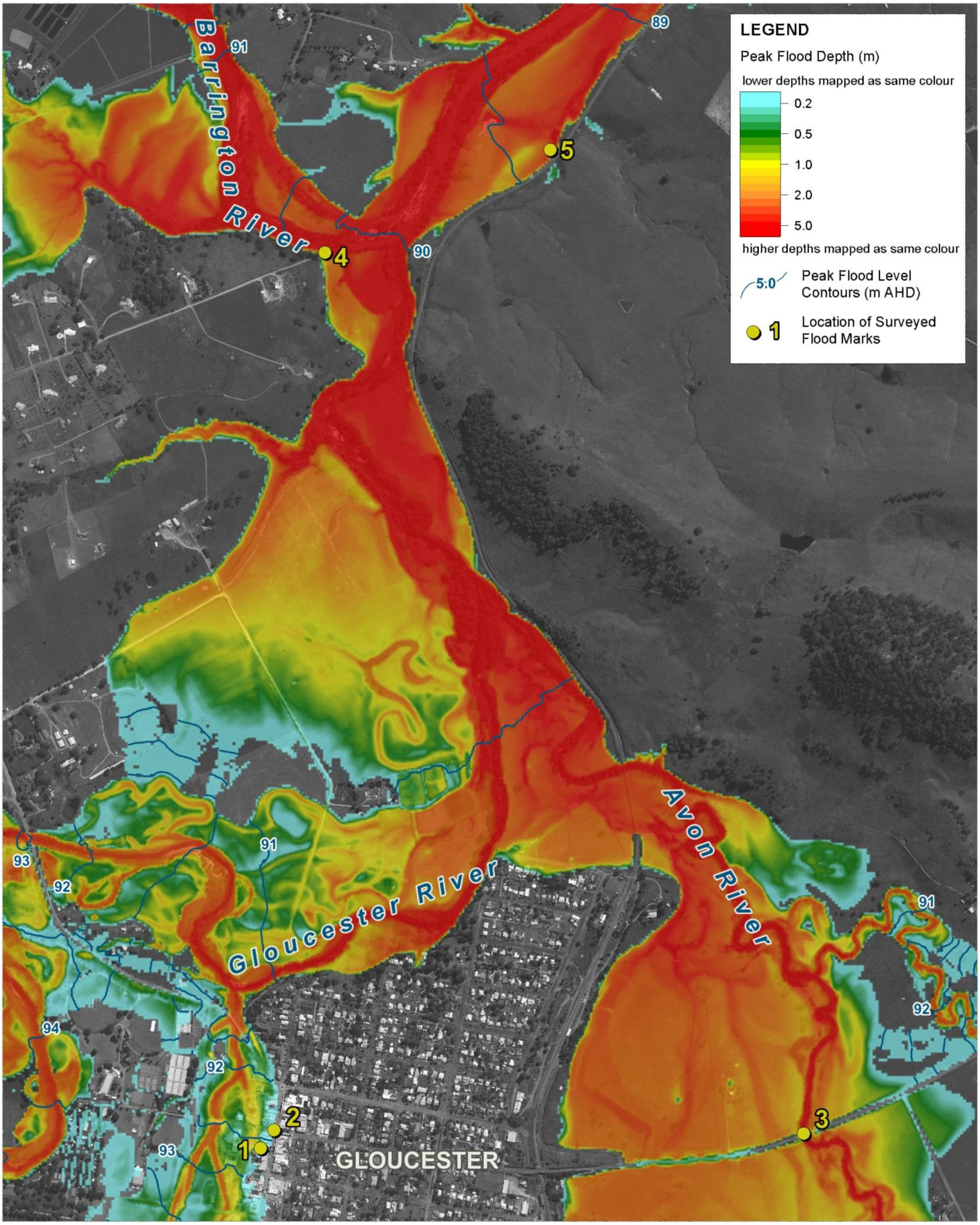
Figure 6-29 Recorded and Modelled Water Levels at Gloucester for the March 1978 Event

In addition to the recorded hydrograph at Gloucester there are a number of peak flood level records around the town. The details of these were provided in the previous flood study. Their location along with flood mapping from the model simulation has been presented on Figure 6-30. A comparison of modelled and recorded flood levels is provided in Table 6-9.

Table 6-9 Modelled and Recorded Flood Levels for the March 1978 Event

ID	Location	Recorded Level (m AHD)	Modelled Level (m AHD)
1	Bakers	92.4	92.6
2	Corner of Church and Denison Streets	92.5	92.4
3	Bucketts Way	90.6	90.8
4	Water Intake	90.3	90.2
5	Railway	88.8	89.4

The two peak flood levels in town have been matched by adjusting the model inflow on the Gloucester River between Forbesdale and Gloucester, to provide the required flow rate through The Billabong. The comparison of flood levels at Bucketts Way indicates that the modelled flows on the Avon River may be overestimated. The modelled level at the railway is also higher than the recorded level, indicating that the combined flood flow of the Gloucester, Avon and Barrington levels is too high in the model. As discussed, uncertainty in the timings and magnitude of flood peaks on the Avon River could account for this, the impact of which is evident in Figure 6-29 at the Gloucester gauge.



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6.6 March 1956 Model Verification

For the March 1956 event there is no continuous rainfall data available and so it is not worthwhile attempting to assess the performance of the hydrological model for this event. There are also no recorded hydrographs available and so a similar approach to that used for March 1978 cannot be adopted. However, peak flood levels are available at the Forbesdale gauges enabling the likely peak flow rates to be estimated. These flows have been used to assess the performance of the hydraulic model at Gloucester.

6.6.1 Rainfall Data

There are no continuous rainfall gauges available from which to establish a temporal rainfall pattern. The only available daily rainfall gauge within the study catchments is the Gloucester Post Office. The record from this gauge totals 174mm over the 1st and 2nd March. Comparison with the design IFDs (1987) suggests that this was between a 50% AEP and 20% AEP rainfall event, or between a 20% AEP and 10% AEP event for the 2013 IFDs. These magnitudes are far below expected given the resultant flooding in Gloucester and it is likely that much heavier rainfall occurred across the upper catchment.

6.6.2 Model Inflows

A truncated version of the TUFLOW model was established, covering the Gloucester River from Sandy Creek to downstream of the Barrington River confluence. The recorded flood level of 128.16m AHD at the Gloucester River Forbesdale gauge indicates a peak flow rate of around 550m^3/s, as derived from the modelled rating curve. Assuming a uniform rainfall distribution across the catchment (as for design rainfall conditions) established that the peak flow rate at Gloucester is typically in the order of 20% larger than that recorded at Forbesdale. A model inflow of 650m^3/s was therefore adopted. A model inflow of 600m^3/s was also tested, given that the rainfall recorded at Gloucester was likely much less than that on the upper catchment.

Assuming a uniform rainfall distribution across the catchment (as for design rainfall conditions) established that the peak flow rate at the Gloucester River confluence is typically in the order of 10% larger than that recorded at Forbesdale. An inflow of 1,250m^3/s was therefore provided for the Barrington River (based on around 1,120m^3/s at Forbesdale plus a 10% increase).

An assumed coincident flow rate of 350m^3/s was adopted for the Avon River. However, the impact of these inflows is insignificant as the flood levels in the confluence area do not impact on the flood levels in Gloucester Town within the expected range.

6.6.3 Downstream Boundary Condition

A range of flood levels were tested at the downstream boundary and were found to have no impact on the modelled flood levels through Gloucester Town. They do have an impact on the flood level at the Gloucester (Lehmans Flat Bridge) gauge location, but not within Gloucester itself. For events of this magnitude the flood levels through Gloucester are driven entirely by the upstream flood flows.

6.6.4 Model Topography

The current model topography was modified to remove the raised embankments of the Thunderbolts Way and Boundary Street in Gloucester. These are present in the 2013 LiDAR elevations, but were most likely lower during the 1956 flood event. However, these were found to have a minimal impact on modelled flood levels within Gloucester town.

6.6.5 Observed and Simulated Flood Behaviour

There are a number of observed peak flood levels in Gloucester for the March 1956 event, which were available from the previous flood study. This enables a comparison with the modelled flood levels at similar locations. Their location along with flood mapping from the model simulation has been presented in Figure 6-31.

A comparison of modelled and recorded flood levels is provided in Table 6-10.

Table 6-10 Modelled and Recorded Flood Levels for the March 1956 Event

ID	Location	Recorded Level (m AHD)	Modelled Level (m AHD) for 600m^3/s	Modelled Level (m AHD) for 650m^3/s
1	Yates & Twomey	93.6	93.6	93.7
2	Hazelwood	92.9	92.9	93.0
3	McIntyre	92.6	92.9	93.0
4	Tulls Butchery	92.4	92.7	92.8
5	Garners General Store	92.4	92.6	92.7
6	McFadgen	92.7	92.8	92.9

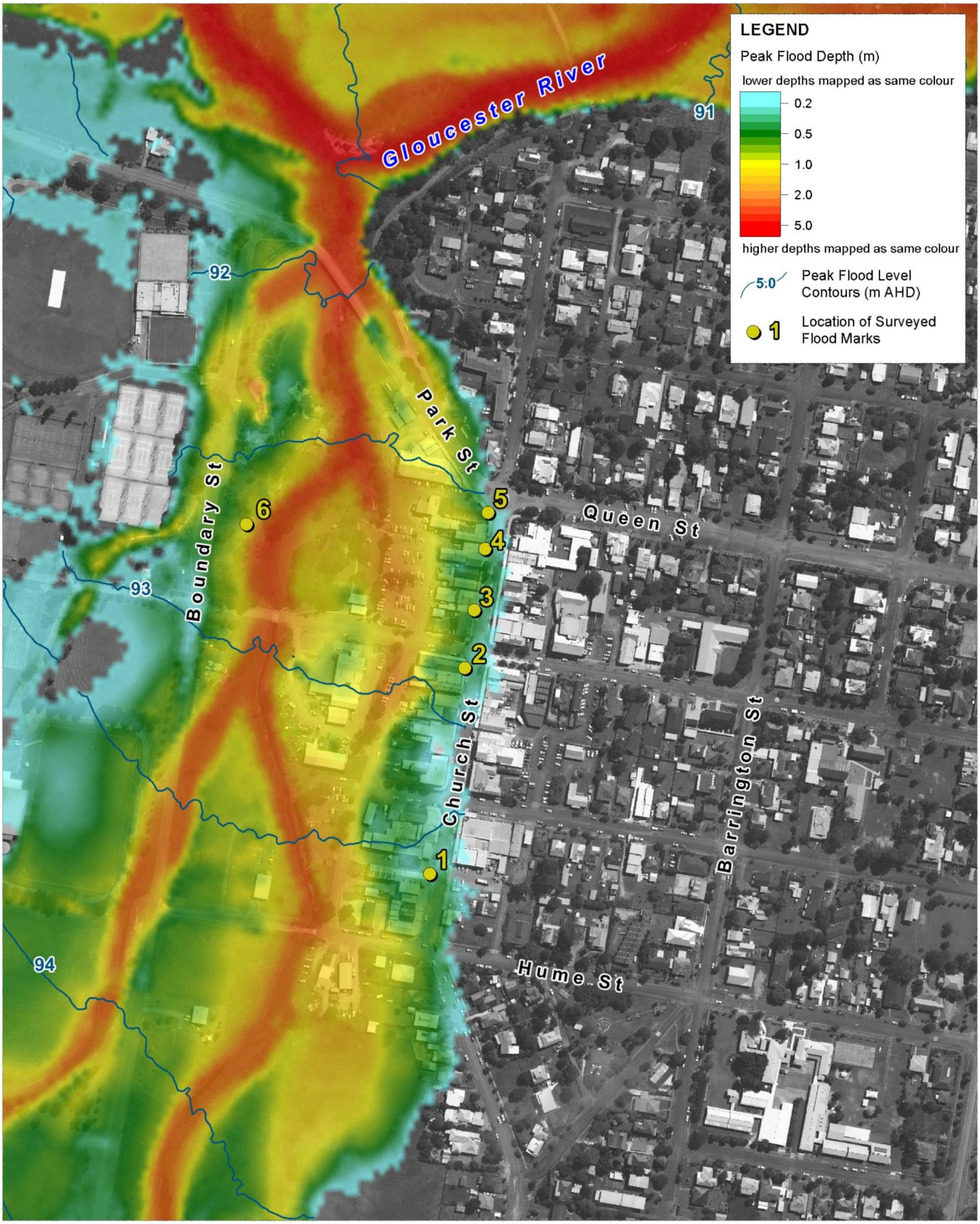
The model results show that the flow assumptions for the Gloucester River provide a good match to the observed data and that potentially the peak flow for the March 1956 event at Gloucester was closer to 600m^3/s than 650m^3/s.

There is a good match for flood levels upstream of Denison Street at locations 1 and 2. However, there is a slight over prediction of flood levels for both flow rates downstream of Denison Street at points 3, 4 and 5. It is understood that since the 1956 event the road levels around the Church Street and Park Street intersection have been raised. It is therefore possible that a steeper flood gradient occurred between Hazelwood and Garners General Store (0.5m) than that which is modelled using the current topography (0.3m).

6.7 February 1929 Model Verification

For the February 1929 event there is no continuous rainfall data available and the stream gauges at Forbesdale were not established. There is therefore limited scope for undertaking a meaningful assessment of model performance. However, there are some peak flood levels available in Gloucester and so the approach for this event has been to ascertain what flow conditions are required for the model to reproduce the observed flood levels.

This approach helps to determine the relative magnitude of the event and provides additional information for the flood frequency analysis, improving the estimation of the design flood conditions.



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6.7.1 Rainfall Data

There are no continuous rainfall gauges available from which to establish a temporal rainfall pattern. The only available daily rainfall gauge within the study catchments is the Gloucester Post Office. The record from this gauge totals 316mm over the 8th and 9th March. Comparison with the design IFDs (1987) suggests that this was around a 2% AEP rainfall event or around a 1% AEP event for the 2013 IFDs. From available anecdotal evidence describing the February 1929 rainfall the previous flood study had estimated that a rainfall depth of 138mm may have occurred over a six hour period. This is also consistent with the design IFDs, suggesting either a 2% AEP or 1% AEP event when adopting the 1987 or 2013 values respectively.

6.7.2 Model Inflows

The truncated version of the TUFLOW model was again used, covering the Gloucester River from Sandy Creek to downstream of the Barrington River confluence. It was found that the flow rate on the Gloucester River that gave the best match to the observed flood levels was around 950m^3/s. Assuming a typical increase in peak flow between Forbesdale and Gloucester of 20% provides for a peak flow of around 800m^3/s on the Gloucester River at Forbesdale. This estimate has been used to improve the flood frequency analysis at the Forbesdale gauge, as discussed in Section 7.3.1.

There is not the data available to accurately determine peak flow rates for the other study catchments. However, a peak flood level recorded on the Gloucester River downstream of the Barrington confluence suggests a peak flow of approximately 3,200m^3/s.

When adopting a uniform rainfall condition across the catchments, such as under design flood conditions, a flow rate of 950m^3/s on the Gloucester River corresponds to a combined peak flow in the Gloucester and Avon Rivers of around 1,600m^3/s. In turn this would suggest that the coincident flow condition on the Barrington River at the time of the Gloucester River flood peak may also have been in the order of 1,600m^3/s.

It can therefore be estimated that the minimum flow rate expected on the Barrington River at Forbesdale for the 1929 event would have been in the order of 1,450m^3/s (assuming around a 10% increase between Forbesdale and the Gloucester River confluence). Given that the timings of the flood peaks on the Barrington and Gloucester Rivers were most likely not exactly coincident, it is feasible that the peak flow at Forbesdale was in excess of 1,500m^3/s. This estimate has been used to improve the flood frequency analysis at the Forbesdale gauge, as discussed in Section 7.3.2.

6.7.3 Downstream Boundary Condition

An appropriate flood level for the downstream boundary condition was derived from an observed flood level on the Gloucester River downstream of the Barrington confluence. It was found that the adopted boundary conditions and coincident flow conditions on the three watercourses have an impact on the flood level at the Gloucester (Lehmans Flat Bridge) gauge location, but only a minimal impact within Gloucester itself.

6.7.4 Model Topography

The adopted model topography is consistent with that adopted for the 1956 flood event.

6.7.5 Observed and Simulated Flood Behaviour

There are a number of observed peak flood levels in Gloucester for the February 1929 event, which were available from the previous flood study. This enables a comparison with the modelled flood levels at similar locations. Their location along with flood mapping from the model simulation has been presented in Figure 6-32.

A comparison of modelled and recorded flood levels is provided in Table 6-11. The model results show that the flow rate of 950m^3/s for the Gloucester River provides a good match to the observed data.

There is a good match for all flood levels except that at location 1. However, the recorded flood level here is lower than that recorded in 1956 and it is similar to the flood level downstream at location 2, when in 1956 there was a level difference of 0.7m. It is therefore likely that the level of 93.5m AHD recorded for the 1929 event is unreliable.

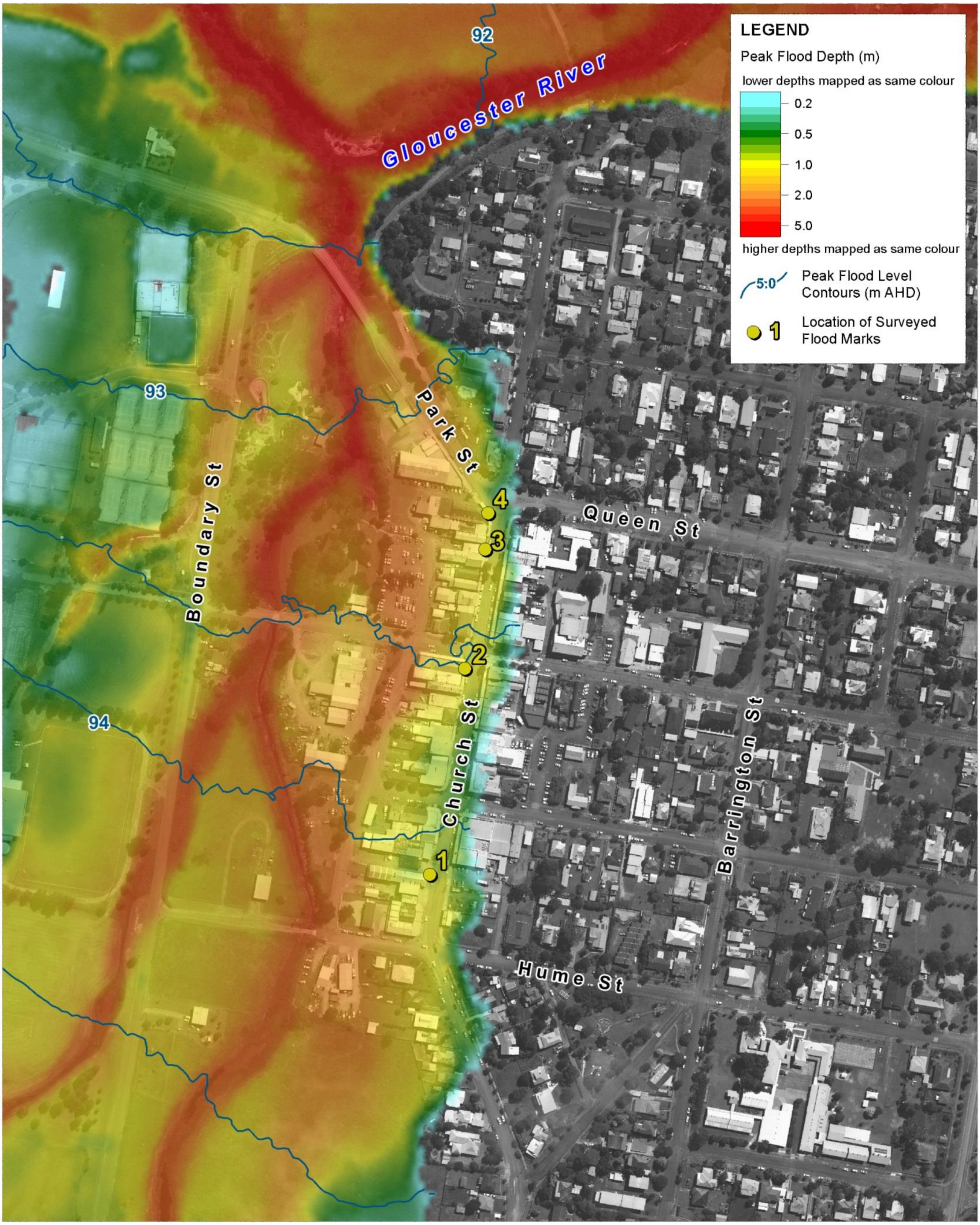
Table 6-11 Modelled and Recorded Flood Levels for the February 1929 Event

ID	Location	Recorded Level (m AHD)	Modelled Level (m AHD) for 950m^3/s
1	Yates & Twomey	93.5	94.1
2	Hazelwood	93.5	93.5
3	Tulls Butchery	93.3	93.3
4	Garners General Store	93.3	93.2

6.8 Calibration Summary

The model calibration process provided an understanding of the nature of flooding within the study catchment. The key findings and results of the process can be summarised as follows:

- There is insufficient data available from which to accurately determine appropriate in-channel roughness values. Appropriate values have therefore been adopted based on literature and previous experience;
- The recent flood events in 2011 and 2013 have enabled the calibration of the hydrological model response to recorded rainfall. This has shown a good match between modelled and recorded hydrographs at the Forbesdale gauges on the Gloucester and Barrington Rivers;
- Recorded flood levels in Gloucester have been used to assess the hydraulic model performance for the 2011, 1978, 1956 and 1929 flood events. This has shown that when the appropriate flow rates on the Gloucester River at Gloucester are reproduced, the hydraulic model provides a good match to recorded flood levels in town; and
- The results of the calibration process provide some level of confidence when taking the hydrologic and hydraulic models through to the estimation of design flood conditions, despite the uncertainties associated with the limited availability of rainfall data.



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February 1929 Model Verification

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7 Design Flood Conditions

7.1 Simulated Design Events

Design floods are hypothetical floods used for planning and floodplain management investigations. They are based on having a probability of occurrence specified as Annual Exceedance Probability (AEP) expressed as a percentage.

Refer to Table 7-1 for a definition of AEP.

Table 7-1 Design Flood Terminology

AEP	Comments
0.2%	A hypothetical flood or combination of floods which represent the worst case scenario with a 0.2% probability of occurring in any given year.
0.5%	As for the 0.2% AEP flood but with a 0.5% probability.
1%	As for the 0.2% AEP flood but with a 1% probability.
2%	As for the 0.2% AEP flood but with a 2% probability.
5%	As for the 0.2% AEP flood but with a 5% probability.
10%	As for the 0.2% AEP flood but with a 10% probability.
20%	As for the 0.2% AEP flood but with a 20% probability.
50%	As for the 0.2% AEP flood but with a 50% probability.
Extreme Flood / PMF[1]	A hypothetical flood or combination of floods which represent an extreme scenario.

1 A PMF (Probable Maximum Flood) is not necessarily the same as an Extreme Flood.

In determining the design floods it is necessary to take into account:

- Design rainfall parameters (rainfall depth, temporal pattern and spatial distribution). These inputs drive the hydrological model from which design flow hydrographs will be extracted as inputs to the hydraulic model;
- Flood frequency analyses at the stream gauge locations. These provide a statistical estimate of design peak flow conditions from the available recorded data and are used in conjunction with the design rainfall outputs from the hydrological model to establish appropriate design flood conditions;

- Coincident flood conditions within the Gloucester, Barrington and Avon Rivers; and
- The potential impact of future climate change on catchment inflows.

In accordance with Council's brief, the design events to be simulated include the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF event. The 1% AEP flood is generally used as a reference flood for development planning and control for residential development.

The adopted storm duration is discussed in Section 7.2.4. The adopted lake downstream boundary conditions are discussed in Section 7.5.

7.2 Design Rainfall

Design rainfall parameters are derived from standard procedures defined in AR&R (2001) which are based on statistical analysis of recorded rainfall data across Australia. The derivation of location specific design rainfall parameters (e.g. rainfall depth and temporal pattern) for the study catchment is presented below.

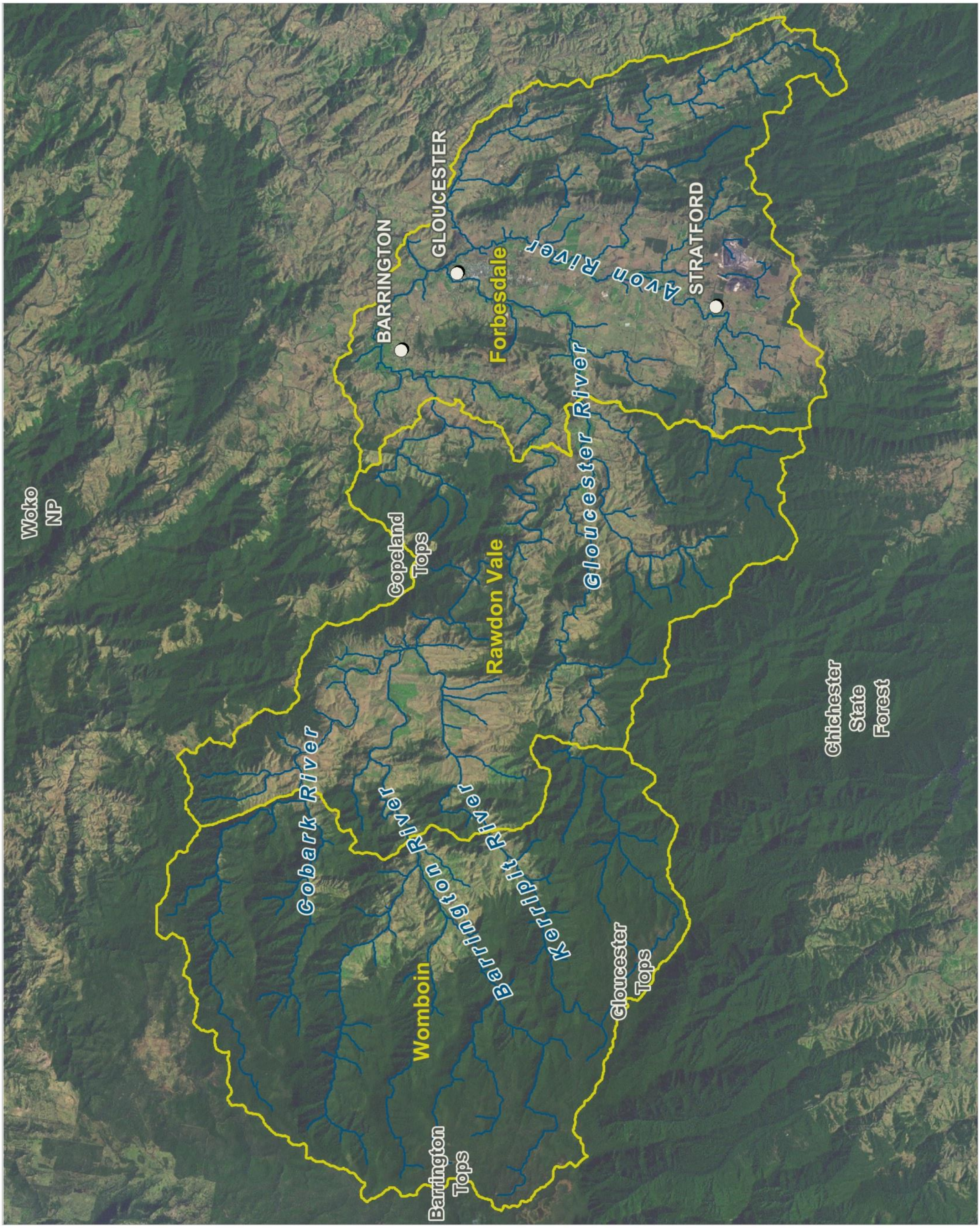
7.2.1 Rainfall Depths

Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves utilising the procedures outlined in AR&R (2001). These curves provide rainfall depths for various design magnitudes (up to the 1% AEP) and for durations from 5 minutes to 72 hours.

The Probable Maximum Precipitation (PMP) is used in deriving the Probable Maximum Flood (PMF) event. The theoretical definition of the PMP is "the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of year" (AR&R, 2001). The ARI of a PMP/PMF event ranges between 10^4 and 10^7 years and is beyond the "credible limit of extrapolation". That is, it is not possible to use rainfall depths determined for the more frequent events (1% AEP and less) to extrapolate the PMP. The PMP has been estimated using the Generalised Southeast Australia Method (GSAM) derived by the Bureau of Meteorology (AR&R, 2001).

Given the relatively large catchment size (1250km^2) and variation in design rainfall parameters across the study area, the catchment was sub-divided into three zones, as presented in Figure 7-1. The sub-division was based on a combination of factors including area, topography and spatial rainfall variation. Individual IFD design rainfall curves were derived for each of the three zones.

The catchment size also required an areal reduction factor to be applied to the design point rainfall depths. This was undertaken using the recommended approach in the AR&R Revision Project 2 – Spatial Patterns of Rainfall. The areal reduction factors determined for each storm duration and catchment are presented in Table 7-2.



Title:

Gloucester River Catchment Design Rainfall Zones

Figure: 7-1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Approx. Scale

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A range of storm durations were modelled in order to identify the critical storm duration for design event flooding in the catchment. Design durations considered ranged from the 12-hour to the 72-hour durations. The 36-hour storm duration was found to be the critical duration for the catchment, as discussed in Section 7.2.4.

Table 7-2 Design Rainfall Areal Reduction Factors

Storm Duration (h)	Gloucester River to The Billabong (250km^2)	Avon River to the d/s Waukivory Creek Gauge (225km^2)	Combined Gloucester & Avon Rivers (550km^2)	Barrington River to the Gloucester Confluence (700km^2)	Combined Gloucester, Avon & Barrington Rivers (1250km^2)
12	0.866	0.871	0.831	0.819	0.787
18	0.889	0.893	0.860	0.850	0.824
24	0.907	0.910	0.880	0.871	0.848
36	0.928	0.931	0.905	0.898	0.878
48	0.940	0.942	0.920	0.913	0.896
72	0.954	0.956	0.937	0.932	0.917

The areal reduction factor for the combined Gloucester and Avon Rivers catchments has been adopted for all design events, as it provides for estimates within 3% of each of the individual and coincident catchment flood conditions that may require consideration from a design perspective.

Table 7-3 shows the average design rainfall intensities for each of the three zones adopted for the 36-hour storm duration, as based on the 1987 AR&R IFDs. The areal reduction factor of 0.905 has been applied. For comparison the equivalent design rainfall intensities using the 2013 AR&R IFDs are presented in Table 7-4 with the ratios between 2013 and 1987 presented in Table 7-5.

The study catchment is situated within the transition zone of the GSAM and GTSM methods for PMP estimation, so both approaches were considered. It was considered that the GTSM provided excessively high estimates of rainfall intensities and so the GSAM was adopted. The GSAM method for the estimation of the PMP provided an average rainfall intensity of 54.4mm/h for the 12-hour storm duration. This was found to be the critical duration for the modelling of the PMF event and was applied across the entire catchment. The PMP calculations were based on the average of the 2% AEP 72-hour duration point rainfall intensities of the three design rainfall zones.

Table 7-3 Average Design Rainfall Intensities (mm/h) AR&R 1987

Design Rainfall Zone	Design Event Frequency (36-hour Storm Duration)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
Womboin	4.10	5.44	6.24	7.32	8.81	9.96	11.2	12.9
Rawdon Vale	4.03	5.35	6.11	7.17	8.59	9.68	10.9	12.5
Forbesdale	3.44	4.55	5.19	6.05	7.23	8.15	9.14	10.4

Table 7-4 Average Design Rainfall Intensities (mm/h) AR&R 2013

Design Rainfall Zone	Design Event Frequency (36-hour Storm Duration)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
Womboin	2.79	3.78	4.46	5.15	6.06	6.78	7.47	8.42
Rawdon Vale	2.84	3.92	4.69	5.47	6.55	7.42	8.28	9.41
Forbesdale	2.71	3.73	4.45	5.17	6.16	6.94	7.69	8.69

Table 7-5 Comparison of 2013 with 1987 Design Rainfall Intensities

Design Rainfall Zone	Design Event Frequency (36-hour Storm Duration)							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
Womboin	0.68	0.69	0.71	0.70	0.69	0.68	0.67	0.65
Rawdon Vale	0.70	0.73	0.77	0.76	0.76	0.77	0.76	0.75
Forbesdale	0.79	0.82	0.86	0.85	0.85	0.85	0.84	0.84

7.2.2 Temporal Patterns

The IFD data presented in Table 7-3 provides for the average intensity (or total depth) that occurs over a given storm duration. Temporal patterns are required to define what percentage of the total rainfall depth occurs over a given time interval throughout the storm duration. The temporal patterns adopted in the current study are based on the standard patterns presented in AR&R (2001). The adopted temporal pattern for the PMP was that of the GSAM detailed in the Hydrology Report Series 5 (BoM, 1998).

7.2.3 Rainfall Losses

Standard initial and continuing loss values of 10mm and 2.5mm/h were adopted, as recommended in AR&R for coastal NSW. These are consistent with those adopted for the calibration and validation events.

7.2.4 Critical Duration

The critical duration is the storm duration for a given event magnitude that provides for the peak flood conditions at the location of interest. For example, small catchments are more prone to flooding during short duration storms, while for large catchments longer durations will be more critical.

The 1% AEP flood event was run for a range of durations between 12-hours and 72-hours, to determine the critical duration for each location in the study area. The critical duration for the Gloucester, Avon and Barrington River catchments was found to be the 36-hour storm.

The PMP has been estimated using the Generalised Southeast Australia Method (GSAM) derived by the Bureau of Meteorology (AR&R, 2001). Design rainfall hyetographs were derived for the 12-hour, 24-hour, 36-hour, 48-hour and 72-hour durations. The critical storm using this method was found to be the 12-hour duration, as it provides the greatest peak flow for the study catchment.

The same temporal pattern has been applied across the whole catchment. This assumes that the design rainfall occurs simultaneously across each of the modelled sub-catchments. The direction of a storm and relative timing of rainfall across the catchment may be determined for historical events if sufficient data exists, however, from a design perspective the same pattern across the catchment is generally adopted.

7.2.5 Coincident Catchment Flood Conditions

The close proximity of the Gloucester, Barrington and Avon River confluences means that the coincident flood conditions in each catchment can have a significant influence on the resultant flooding around the confluence area. The adopted design flood conditions have assumed coincident flooding of the same magnitude across all three study catchments. An appropriate design flood condition has been determined for each catchment in isolation and then the same design flood condition applied to each coincidently.

Reference to A range of storm durations were modelled in order to identify the critical storm duration for design event flooding in the catchment. Design durations considered ranged from the 12-hour to the 72-hour durations. The 36-hour storm duration was found to be the critical duration for the catchment, as discussed in Section 7.2.4.

Table 7-2 indicates that this approach may overestimate the combined flood flow conditions by the order of 2% to 5% (through comparison of the appropriate areal reduction factors for individual catchments to that for the three catchments combined). This difference is relatively insignificant compared to other uncertainties (such as the estimation of design flood flows) and shows that the adopted design flood conditions at and downstream of the confluence area are not overly conservative.

However, each actual flood event is likely to have a different flood condition in each of the catchments. It is therefore important to understand what the implications for this are on the resultant flood levels around the confluence area, how this may impact on flooding within Gloucester and what the extent of the coincident flooding influence is.

To test the impact of different flood conditions occurring in each of the catchments a series of sensitivity tests has been undertaken. This consisted of a total of nine scenarios representing:

- A 5% AEP flood condition in each individual catchment coincident with a 20% AEP flood condition in the other two catchments;
- A 1% AEP flood condition in each individual catchment coincident with a 5% AEP flood condition in the other two catchments; and
- A 0.2% AEP flood condition in each individual catchment coincident with a 1% AEP flood condition in the other two catchments.

7.3 Flood Frequency Analyses

The Gloucester River at Forbesdale and Barrington River at Forbesdale water level gauges have been in operation since the 1940s and as such offered sufficient data to undertake a flood frequency analysis at these sites. Annual maxima water levels were extracted from the available data at each of the sites. The hydraulic model was used to derive a rating curve at the gauging sites, from which the recorded flood levels were converted to flows. The TUFLOW FLIKE extreme value analysis package was used to undertake the flood frequency analyses.

Developed by Professor George Kuczera from the School of Civil Engineering at the University of Newcastle Australia, TUFLOW FLIKE is compliant with the recent major revision of industry guidelines for flood estimation, documented in the draft update of Australian Rainfall and Runoff (ARR).

The analyses used a Bayesian inference method with both the Log Pearson III (LPIII) and Generalised Extreme Value (GEV) probability models.

7.3.1 Gloucester River at Forbesdale

The Gloucester River analysis had a total of 45 annual maxima available, of which the lowest five were excluded from the analysis. The 1929 flood was also included beyond the period of gauge record, assuming a single occurrence above a threshold flow of 700m^3/s in the years between 1929 and the start of the gauge record in 1949. This was based on the estimated peak flow of 800m^3/s detailed in Section 6.7.

The fitted LPIII and GEV distributions are presented on Figure 7-2 along with the 90% confidence limits and plotting positions of the observed annual maxima.

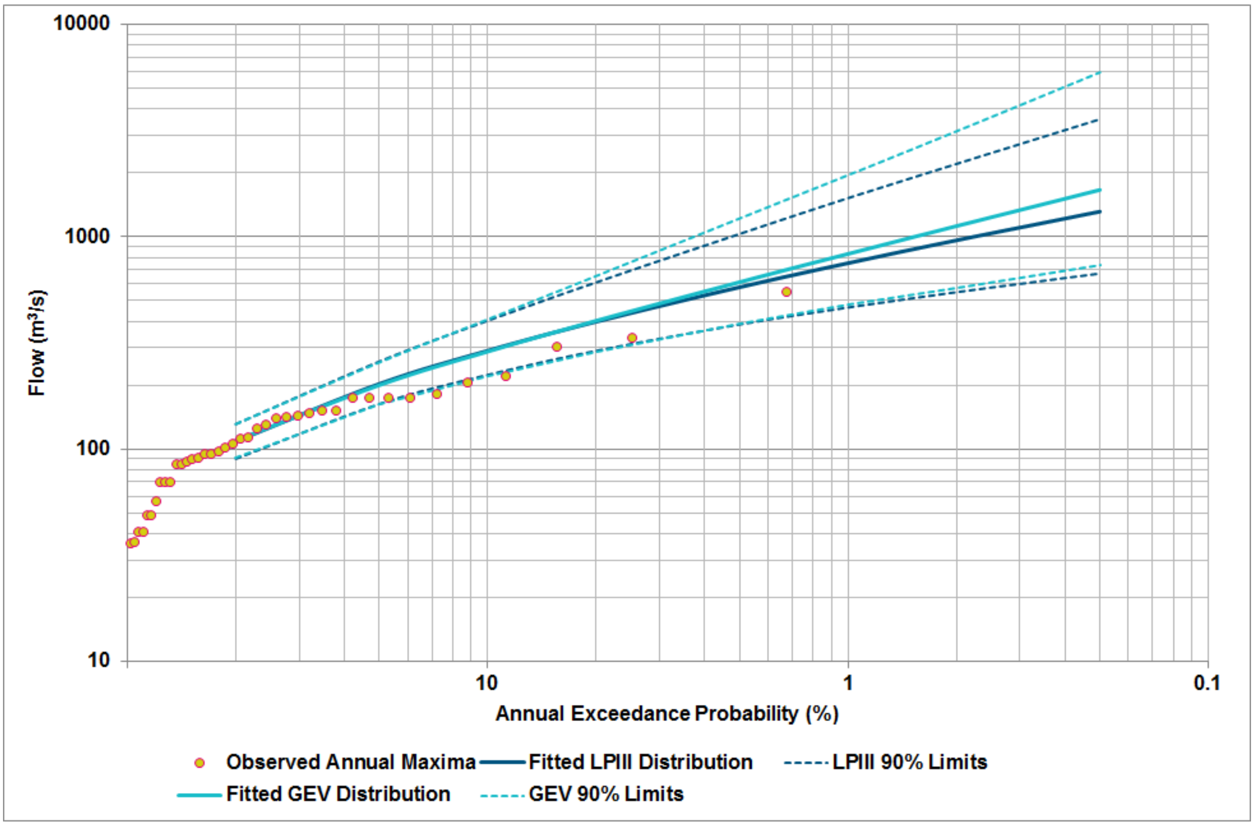


Figure 7-2 Flood Frequency Analysis for the Gloucester River at Forbesdale

7.3.2 Barrington River at Forbesdale

The Barrington River analysis had a total of 65 annual maxima available, of which the lowest two were excluded from the analysis. The 1929 flood was also included beyond the period of gauge record, assuming a single occurrence above a threshold flow of 1500m^3/s in the years between 1929 and the start of the gauge record in 1946. This was based on the estimated peak flow of 1800m^3/s detailed in Section 6.7.

The fitted LPIII and GEV distributions are presented on Figure 7-3 along with the 90% confidence limits and plotting positions of the observed annual maxima.

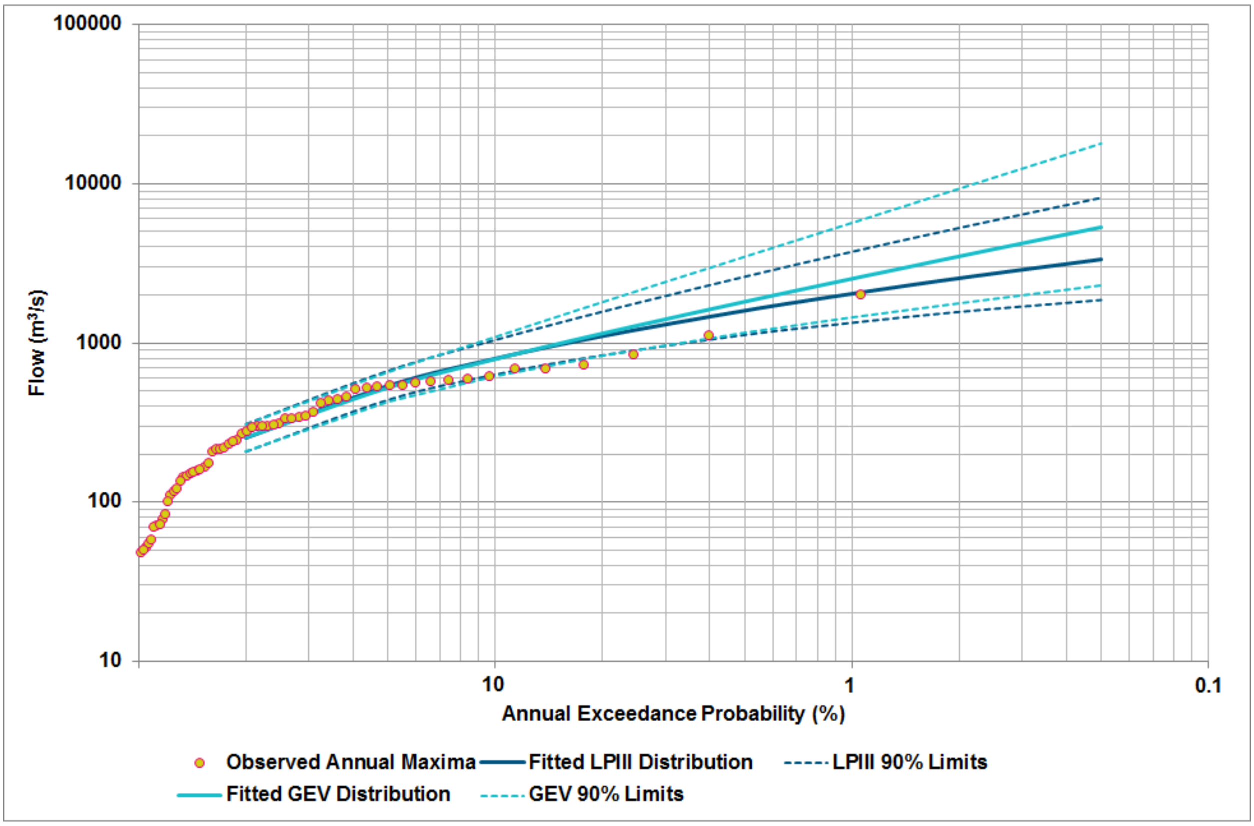


Figure 7-3 Flood Frequency Analysis for the Barrington River at Forbesdale

7.3.3 Avon River

There is no long-term gauge record available on the Avon River from which to undertake a flood frequency analysis. The gauge downstream of the Waukivory Creek confluence has been in operation since 2004. The rating curve at this gauging site is also extremely flat for out-of-bank flows, which introduces a large amount of uncertainty to the estimation of flood flows. No flood frequency analysis has therefore been undertaken on the Avon River.

7.4 Adopted Design Flows

7.4.1 Design Peak Flows

The derived design rainfall distributions were simulated in the RAFTS hydrological model to derive design flows at the Forbesdale gauges. The peak flow rates derived from this rainfall runoff approach differed to those derived through the flood frequency analyses, as presented in Table 7-6 and Table 7-7.

Table 7-6 Derived Design Flows (m^3/s) for the Gloucester River at Forbesdale

Method	Design Event Frequency							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
RR 1987 IFDs	285	464	575	729	891	1046	1225	1463
RR 2013 IFDs	132	260	356	459	571	683	802	959
Fitted LPIII	109	203	291	398	579	752	964	1315
Fitted GEV	110	200	288	403	612	832	1124	1665

Table 7-7 Derived Design Flows (m^3/s) for the Barrington River at Forbesdale

Method	Design Event Frequency							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
RR 1987 IFDs	756	1241	1551	1966	2432	2884	3382	4067
RR 2013 IFDs	342	670	922	1185	1476	1767	2071	2489
Fitted LPIII	254	538	798	1105	1596	2039	2553	3354
Fitted GEV	255	524	792	1148	1816	2531	3502	5340

For the more frequent flood events (50% AEP to 5% AEP) the rainfall runoff modelling produced large flow estimates than the flood frequency analyses, substantially so when adopting the standard 1987 IFDs. Given the length of record available at the gauging sites it is expected that the frequency analysis estimates should be reasonably reliable for these events. Much of the over prediction of design flows by the rainfall runoff modelling is attributed to the 1987 design IFDs.

It is also possible that the distribution of relative intensities within the design temporal pattern is not representative of observed conditions within the study area. Comparisons of the design temporal pattern with those of the recent flood events suggest this possibility (for the more frequent flood event magnitudes at least), as presented in Figure 7-4.

A series of peak design flows has been adopted that takes the flow estimates derived from each method into consideration. A comparison of the derived and adopted design flows is presented in Figure 7-5 and Figure 7-6.

For events between the 50% AEP and 2% AEP there is a reasonable agreement between the flood frequency analyses and the rainfall runoff modelling using the 2013 IFDs. However, the 2013 IFDs provide significantly lower estimates than the other methods for the larger magnitude flood events. It is not yet recommended to adopt the 2013 IFDs until the AR&R revision of design rainfall temporal patterns has been completed. It is possible that the revised temporal patterns may see the rainfall runoff flows increase for the larger magnitude flood events.

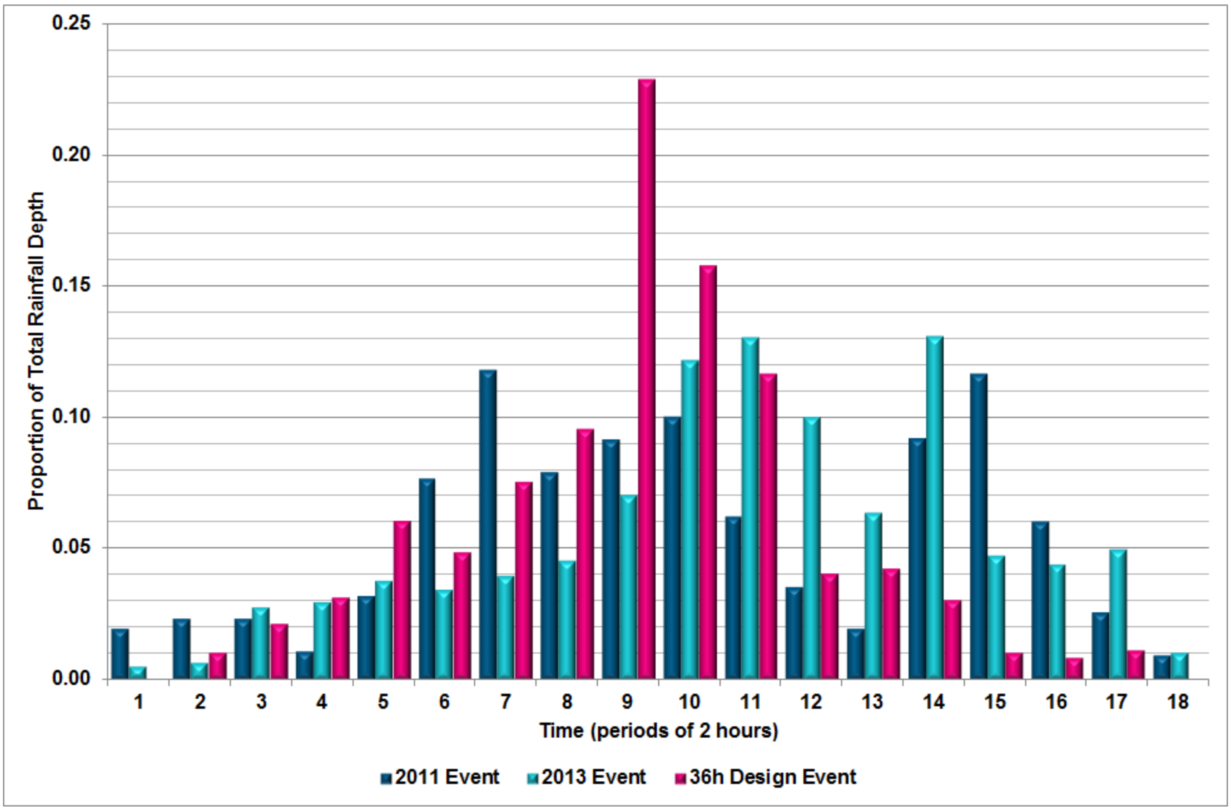


Figure 7-4 Comparison of Observed and Design Rainfall Temporal Patterns

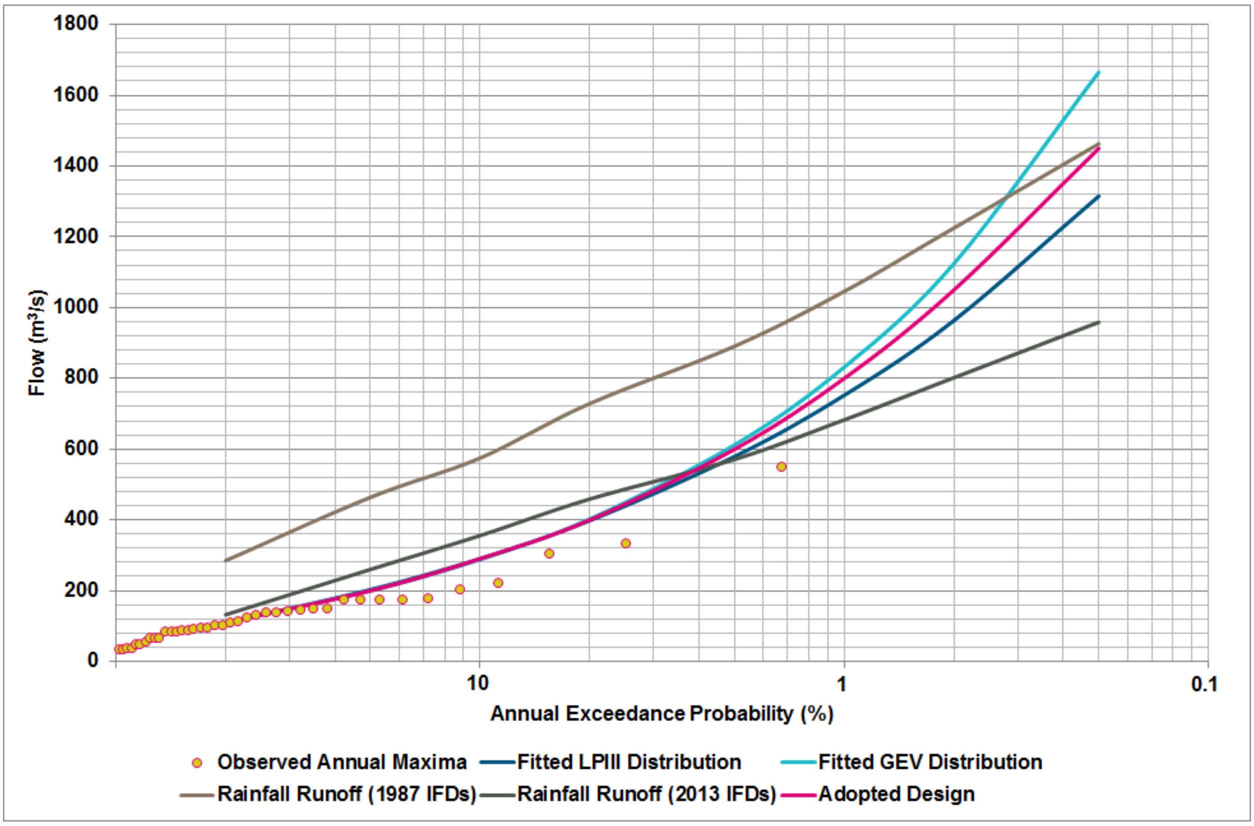


Figure 7-5 Derived and Adopted Design Flows for the Gloucester River at Forbesdale

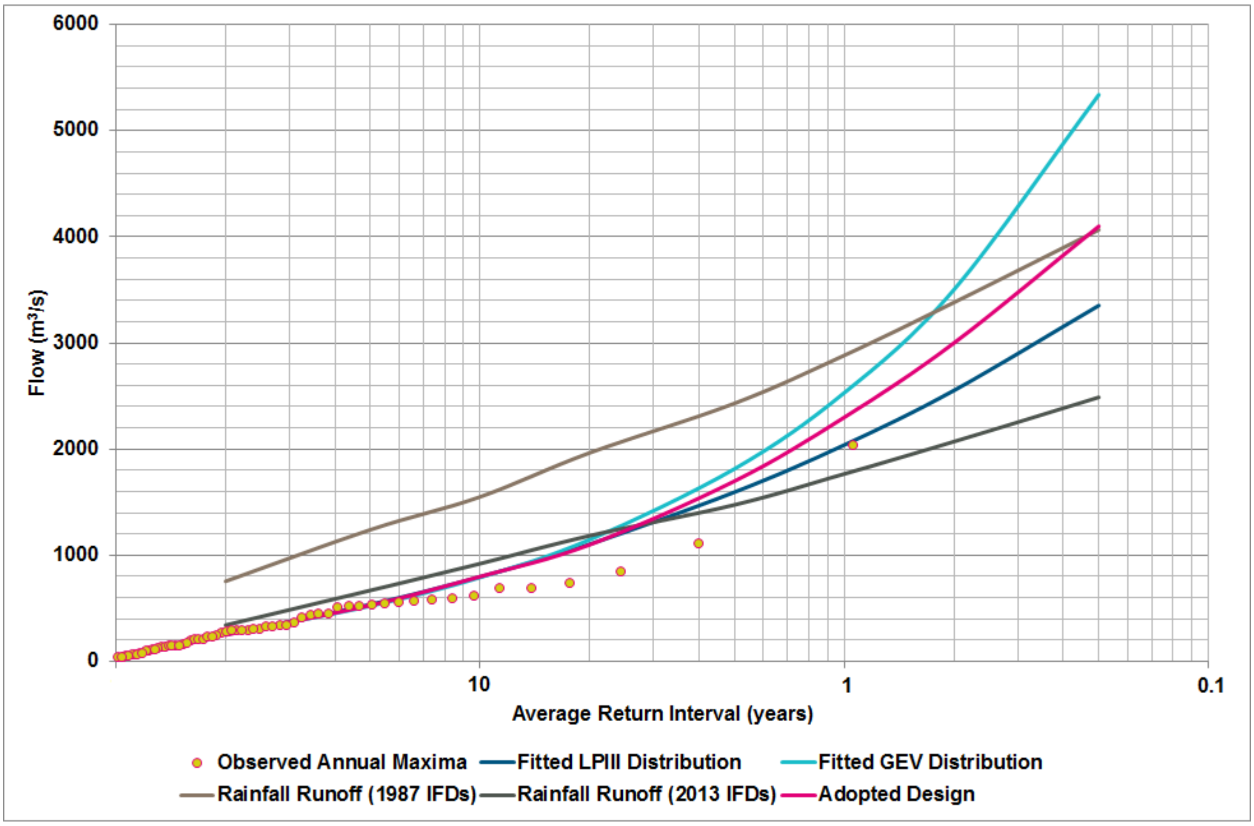


Figure 7-6 Derived and Adopted Design Flows for the Barrington River at Forbesdale

7.4.2 Design Hydrograph Shape

In order to derive design inflow hydrographs for the TUFLOW model the 1987 AR&R design rainfall IFDs and temporal patterns have been used in the RAFTS hydrological model. The output hydrographs have then been scaled to match the adopted peak flows. The 48-hour duration storm has been adopted to derive the design hydrograph shape. The 36-hour storm duration was found to be the critical condition, but it is not necessary to adopt this when scaling the flow hydrographs to match alternative target peak flows.

The 36-hour and 48-hour rainfall temporal patterns produce similar shaped hydrographs, albeit with the 48-hour duration storm providing for a small amount of additional runoff volume. The calibration process had identified the potential for the hydrograph recession volume to be underestimated, due to a significant interflow component that is not represented within RAFTS. It is therefore reasonable to provide some additional volume to the design flood hydrographs in an attempt to account for this. Table 7-8 shows the differences in total runoff volume for each of the design events on the Gloucester River at Forbesdale when adopting either the 36-hour or 48-hour design storm duration.

It can be seen that the 48-hour storm duration hydrograph provides for around a 10% increase in total runoff volume when compared to adopting the 36-hour storm duration. The increase varies from around 7% for the 50% AEP event to around 13% for the 0.2% AEP event. The peak flow rates for each duration are similar, as they have been scaled to match the adopted design peak flows. Figure 7-7 shows the difference in 1% AEP hydrograph shape on the Gloucester River at Forbesdale when adopting either the 36-hour or 48-hour storm duration. It can be seen that the hydrograph shapes are reasonably similar, with a consistent peak flow of 800m^3/s. However, the 48-hour storm duration provides an increased volume when flow rates are below around 500m^3/s.

Table 7-8 Gloucester River at Forbesdale 36-hour and 48-hour Runoff Volumes

Design Event	36h Runoff Volume (ML)	48h Runoff Volume (ML)	Increase
50% AEP	6,140	6,560	7%
20% AEP	10,500	11,200	7%
10% AEP	14,900	15,900	7%
5% AEP	20,000	21,600	8%
2% AEP	30,500	33,500	10%
1% AEP	40,300	44,800	11%
0.5% AEP	52,200	58,800	13%
0.2% AEP	71,700	81,000	13%

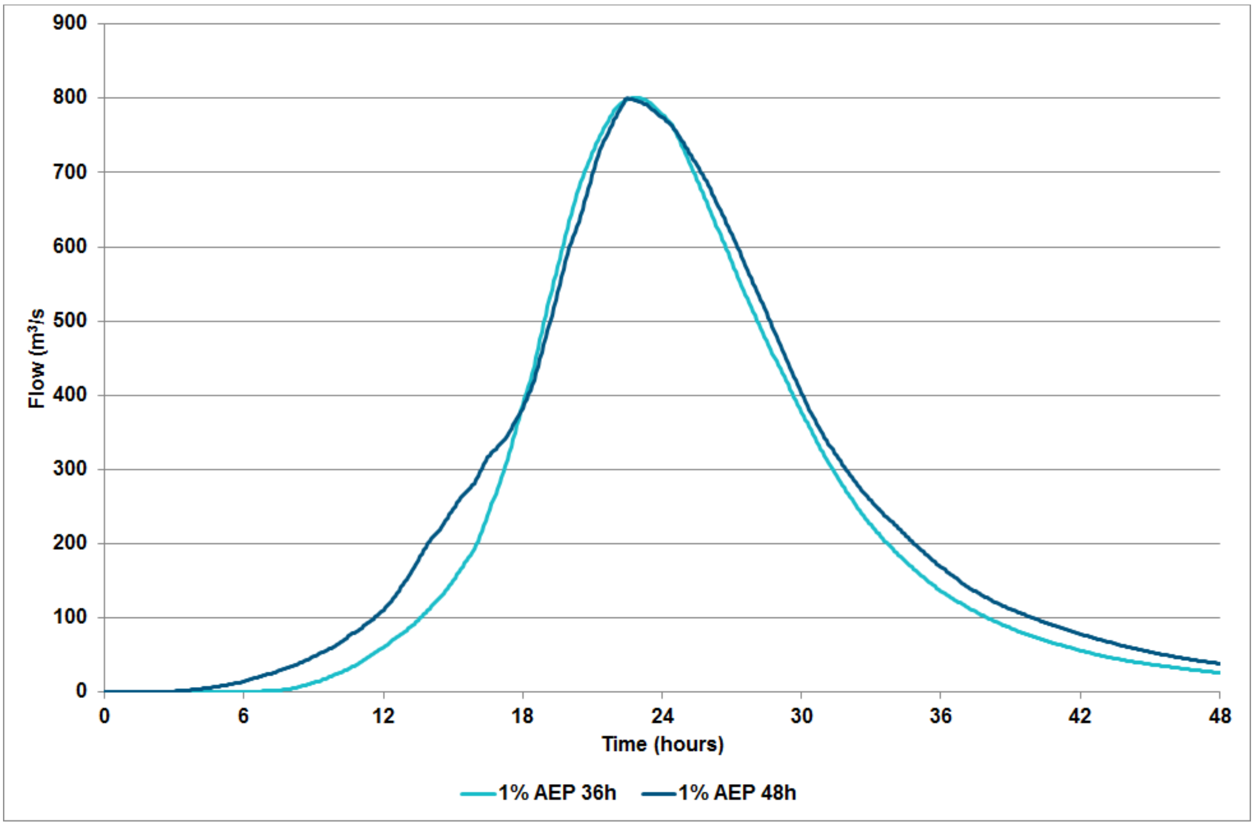


Figure 7-7 Gloucester River at Forbesdale 1% AEP 36-hour and 48-hour Flow Hydrographs

7.4.3 Design Flow Scaling Factors

The peak flow rates for the 48-hour design storms simulated in the hydrological model and the scaling factors required to match the adopted design peak flows for the Gloucester River at Forbesdale are presented in Table 7-9. The adopted scaling factors for the Barrington River at

Forbesdale are presented in Table 7-10. The tables show that the required scaling factors on the Gloucester River and Barrington River are similar, being within 0.015 for each event except the 50% AEP, which is within 0.059. The scaling factors are lowest for the 50% AEP event and increase with event magnitude.

Table 7-9 Gloucester River at Forbesdale Design Flow Scaling Factors

Design Event	RAFTS 48h Peak Flow (m^3/s)	Design Peak Flow (m^3/s)	Scaling Factor
50% AEP	272	110	0.404
20% AEP	437	200	0.458
10% AEP	546	290	0.531
5% AEP	688	400	0.581
2% AEP	839	600	0.715
1% AEP	988	800	0.810
0.5% AEP	1160	1050	0.905
0.2% AEP	1382	1450	1.049

Table 7-10 Barrington River at Forbesdale Design Flow Scaling Factors

Design Event	RAFTS 48h Peak Flow (m^3/s)	Design Peak Flow (m^3/s)	Scaling Factor
50% AEP	725	250	0.345
20% AEP	1184	530	0.448
10% AEP	1495	800	0.535
5% AEP	1893	1100	0.581
2% AEP	2336	1700	0.728
1% AEP	2788	2300	0.825
0.5% AEP	3298	3000	0.910
0.2% AEP	3967	4100	1.034

No flood frequency analysis was undertaken for the Avon River and so the design flows are more reliant on the outputs of the hydrological modelling. Given that the design rainfall conditions provide significant over estimations of design flows on the Gloucester and Barrington Rivers it is appropriate to apply similar scaling factors to the model inflows on the Avon River. However, a significant contributor to the over estimation of design flows on the Gloucester and Barrington Rivers in the hydrological modelling is the apparent overestimation of design rainfall depths in the 1987 IFDs (supported by a rainfall frequency analysis at the Gloucester Post Office gauge).

From Figure 7-1 it can be seen that flows on the Gloucester and Barrington Rivers are driven by rainfall from the Womboin and Rawdon Vale design rainfall zones, whereas flows on the Avon River are driven principally by rainfall from the Forbesdale design rainfall zone. From Table 7-5 it can be seen that the average ratio of the 2013 IFDs to the 1987 IFDs across the Womboin and Rawdon Vale design rainfall zones is around 0.72. For the Forbesdale design rainfall zone this is around 0.84 (approximately 17% higher). This suggests that the required reduction to the 1987

IFDs (and hence reduction to the modelled RAFTS design flows) would be lower for the Avon River than that required for the Gloucester and Barrington Rivers.

Adopting a similar scaling factor on the Avon River to those applied on the Gloucester and Barrington Rivers could potentially be under estimating design flows. Therefore the adopted scaling factor for the modelled RAFTS flow hydrographs on the Avon River has been based on the average scaling factor applied on the Gloucester and Barrington Rivers, with a 17% increase to account for the difference in design IFDs across their respective catchments (e.g. (0.404+0.345)/2 x 1.17 = 0.438). Table 7-11 shows the adopted scaling factors on the Gloucester and Barrington Rivers and those applied to model inflows on the Avon River.

The TUFLOW model inflows for RAFTS sub-catchments B55 (Gloucester River at Forbesdale) and B56 (Upper Avon River) have had the scaling factors in Table 7-9 applied to the modelled RAFTS hydrographs. Model inflows for RAFTS sub-catchments B48 (Barrington River at Forbesdale) and B61 (Copeland Creek) have had the scaling factors in Table 7-10 applied. All other TUFLOW model inflows (which reside within the Forbesdale design rainfall zone) have had the Avon River scaling factors from Table 7-11 applied. No scaling factors were applied to the PMF model simulations.

Table 7-11 Avon River Design Flow Scaling Factors

Design Event	Gloucester River Scaling Factor	Barrington River Scaling Factor	Avon River Scaling Factor
50% AEP	0.404	0.345	0.438
20% AEP	0.458	0.448	0.530
10% AEP	0.531	0.535	0.624
5% AEP	0.581	0.581	0.680
2% AEP	0.715	0.728	0.844
1% AEP	0.810	0.825	0.956
0.5% AEP	0.905	0.910	1.062
0.2% AEP	1.049	1.034	1.218

7.5 Downstream Boundary Conditions

The adopted downstream boundary conditions can have a significant impact on modelled flood levels in the lower reaches of the Gloucester, Barrington and Avon Rivers. The flood levels along the Gloucester River downstream of the Barrington River confluence are influenced by the combined inflow from the three study catchments and also potentially from inflows on the Bowman River, which is situated around 4km downstream of the Barrington River.

To avoid the added complication of incorporating the Bowman River into the design flood modelling the downstream model boundary was located just upstream of the Bowman River. A natural constriction in the floodplain (known locally as Old Black Ridge) is situated some 1.5km upstream and provides a control between the Barrington River and the downstream boundary location, which will help limit the influence of the boundary back at the confluence area.

In order to establish appropriate flood levels at the boundary location a simple TUFLOW model was developed, covering around a 10km length of the Gloucester River – from the Barrington River confluence to around 6km downstream of the identified boundary location. A range of flow conditions were simulated through this local model to derive corresponding flood levels at the downstream boundary location of the primary TUFLOW model. Design inflows were provided on the Gloucester (and Avon) River and the Barrington River. An approximation of the Bowman River contribution was made by assuming a similar inflow to the design conditions on the Gloucester River downstream of the Sandy Creek confluence (which has a similar contributing catchment area of around 230km^2).

From the simulations of the local TUFLOW model a flow vs. level relationship at the primary TUFLOW model downstream boundary was established, as presented in Figure 7-8. The adopted design levels are provided in Table 7-12 and were applied as a fixed level boundary to aid model stability.

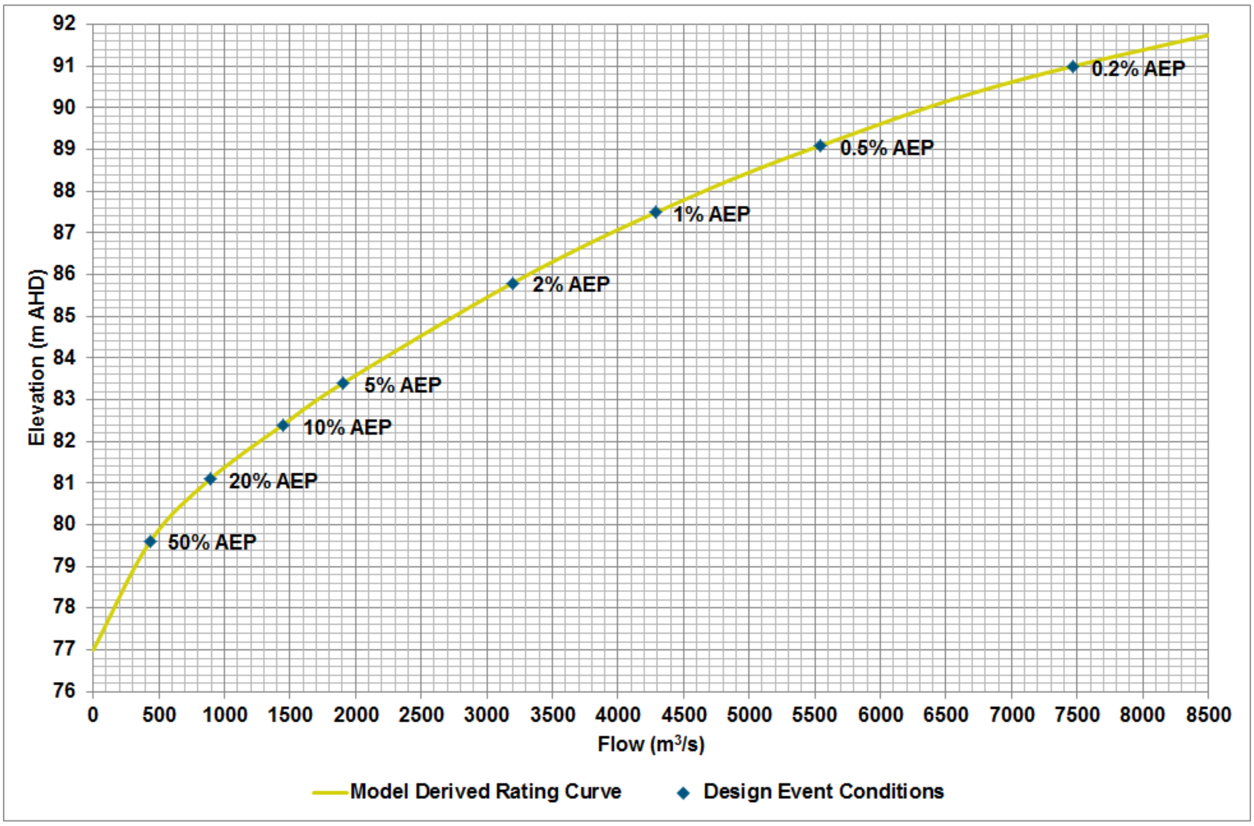


Figure 7-8 Design Downstream Boundary Conditions

7.6 Climate Change

Current research predicts that a likely outcome of future climatic change will be an increase in flood producing rainfall intensities. Climate Change in New South Wales (CSIRO, 2007) provides projected increases in 2.5% AEP 24h duration summer rainfall depths for the study catchments of up to 12% and 10%, for the years 2030 and 2070 respectively. The 2.5% AEP 72h duration summer rainfall depth projections are increases of 22% and 15%, for the years 2030 and 2070 respectively

Table 7-12 Adopted Design Flood Levels at the Downstream Boundary

Design Event	Adopted Downstream Boundary Flood Level (m AHD)
50% AEP	79.6
20% AEP	81.1
10% AEP	82.4
5% AEP	83.4
2% AEP	85.8
1% AEP	87.5
0.5% AEP	89.1
0.2% AEP	91.0
PMF	96.0

The NSW Government has also released a guideline (DECC, 2007) for Practical Consideration of Climate Change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%.

In line with this guidance note, additional tests incorporating a 10% increase to the 1% AEP design rainfall has been undertaken. The design flows for the 0.5% AEP event are around 30% higher than those of the 1% AEP and so comparison of these two events provides an appropriate assessment for potential impacts of a 30% increase in design rainfall depths.

8 Design Flood Results

A range of design flood conditions were modelled, the results of which are presented and discussed below. The simulated design events included the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and 0.2% AEP. The PMF event has also been modelled. The impact of future climate change on flooding in the study catchment was also considered for the 1% AEP design flood event.

The design flood results are presented in a separate mapping compendium. For the simulated design events including the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and PMF events, a map of peak flood level, depth and velocity is presented covering the modelled area. The model results represent flood conditions of the Barrington River downstream of Forbesdale, the Gloucester River downstream of Forbesdale, the Avon River and the associated floodplains.

The downstream extent of the Mograni Creek, Oaky Creek, Waukivory Creek and Dog Trap Creek tributaries are included as an extension of the Avon River floodplain. For these smaller tributaries the model may not represent the critical flood condition, as shorter duration flood events and a more detailed hydrological representation need to be considered to accurately define local flood behaviour.

8.1 Gloucester Town

8.1.1 Flood Behaviour

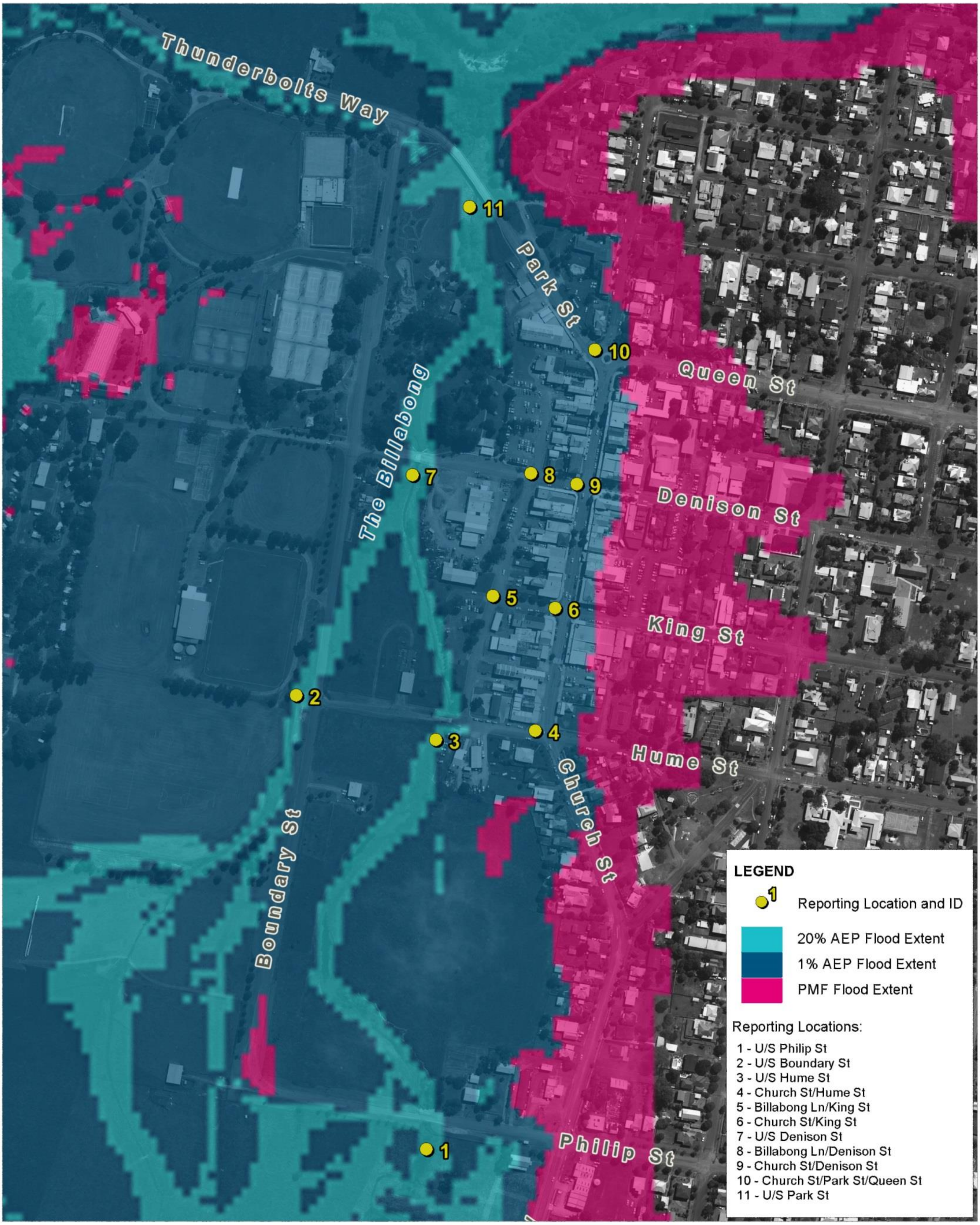
The principal flood mechanism in Gloucester is the spilling of flood waters from the Gloucester River into The Billabong, which is a backwater of the Gloucester River and the local drainage line for western Gloucester. From the 20% AEP event the channel capacity of the Gloucester River is exceeded and flood waters spill from the right bank between Sandy Creek and the caravan park. Flood waters flowing through The Billabong return to the Gloucester River just downstream of the Thunderbolts Way bridge.

From the 10% AEP event flood flows exceed the capacity of The Billabong and flow along Billabong Lane, which was formerly another channel branch of The Billabong. From the 2% AEP event flood waters along The Billabong rise sufficiently high to surround the commercial properties and flow along Church Street, as occurred in the 1956 and 1929 flood events.

Properties situated at the northern edge of Town along the Gloucester River are at risk of flooding from combined flood flows on the Gloucester and Avon Rivers, and to some extent the Barrington River. Inundation to properties along Macleay Street begins to occur around the 2% AEP event. At the 0.2% AEP and PMF events properties along the eastern side of town also become inundated from flooding on the Avon River.

8.1.2 Peak Flood Conditions

Modelled peak flood levels at selected locations (as presented in Figure 8-1) are shown in Table 8-1, for the full range of design flood events considered.



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Design Flood Inundation Extents and Reporting Locations for Gloucester Town	8-1	A

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Approx. Scale

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Table 8-1 Modelled Peak Flood Levels (m AHD) for Design Flood Events in Gloucester Town

ID	Reporting Location	Flood Event Frequency								
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
1	U/S Philip St	93.9	94.1	94.6	94.8	95.2	95.5	95.7	96.6	102.4
2	U/S Boundary St	-	91.9	92.9	93.3	93.9	94.3	94.8	96.5	102.4
3	U/S Hume St	92.0	92.3	93.0	93.3	93.9	94.3	94.8	96.5	102.4
4	Church St/Hume St	-	-	-	93.3	93.9	94.2	94.8	96.5	102.4
5	Billabong Ln/King St	-	-	92.6	92.9	93.5	93.9	94.7	96.5	102.4
6	Church St/King St	-	-	-	-	93.5	93.9	94.7	96.5	102.4
7	U/S Denison St	90.5	91.3	92.2	92.5	93.2	93.6	94.6	96.5	102.4
8	Billabong Ln/Denison St	-	-	91.8	92.4	93.1	93.5	94.6	96.5	102.4
9	Church St/Denison St	-	-	-	92.4	93.1	93.5	94.6	96.5	102.4
10	Church St/ParkSt/Queen St	-	-	-	-	92.7	93.3	94.6	96.5	102.4
11	U/S Park St	89.8	90.6	91.1	91.4	92.4	93.2	94.5	96.4	102.4

A partial flood frequency analysis of the recorded flood levels at the Gloucester gauge has been undertaken and is presented in Figure 8-2. The observed historic flood level data has been used to calculate plotting positions using the Cunnane formula.

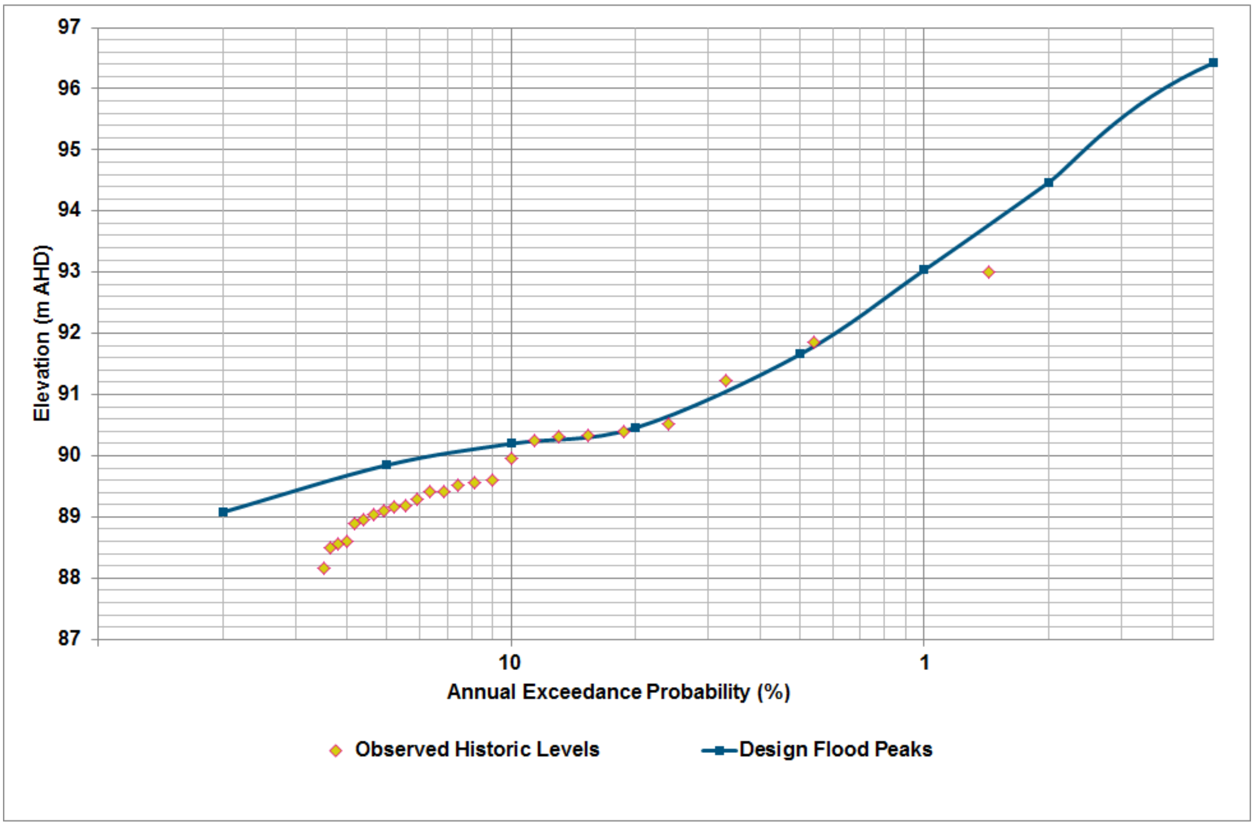


Figure 8-2 Flood Frequency Analysis of Peak Flood Levels at the Gloucester Gauge

The peak level of the 1929 flood has been estimated using the design flood reasults for the 1% AEP event (which is of a similar magnitude) and is expected to have been around 93m AHD, given the peak flood level of around 93.5m AHD at the Church Street and Denison Street intersection.

The observed data is of insufficient quality to derive a definitive flood frequency distribution. The modelled peak flood levels at the gauge from the design flood events have been plotted against the observed data for comparison. It can be seen that the modelled levels provide a good match to the observed throught the 10% AEP to 2% AEP range. For the frequent flood events such as the 50% AEP and 20% AEP the adopted coincident flood conditions are more conservative than the records suggest. The calculated plotting position of the 1929 event is fairly uncertain, but still mathces reasonably well to the modelled 1% AEP design condition.

A similar analysis has also been undertaken for the available data at the Church Street and Denison Street intersection and is presented in Figure 8-3. The modelled flood levels provide a good match to the observed throughout the 5% AEP to 1% AEP range. Given the small sample size there is a large amount of uncertainty associated with the calculated plotting position of the 1929 event, which is calculated at around a 0.5% AEP magnitude, compared to the modelled magnitude of around the 1% AEP.

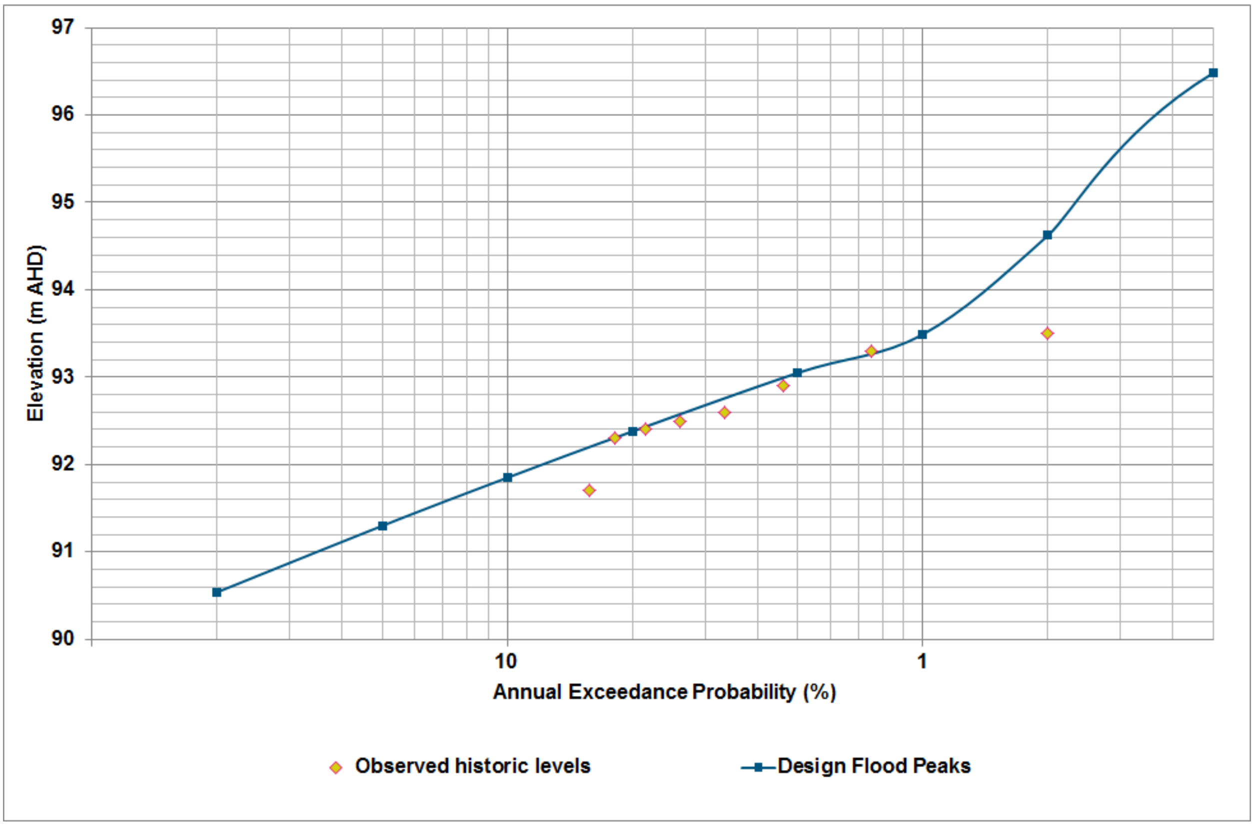


Figure 8-3 Flood Frequency Analysis of Peak Flood Levels at the Church Street and Denison Street Intersection

8.1.3 Flood Flows

Modelled peak flood flows for The Billabong upstream of the Denison Street crossing are shown in Table 8-2 for the full range of design flood events considered. The flood hydrographs at this location are presented in Figure 8-4.

Table 8-2 Modelled Peak Flows (m^3/s) for Design Flood Events, Gloucester Town

ID	Reporting Location	Flood Event Frequency								
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
7	U/S Denison St	1	5	90	160	350	540	780	1070	1680

Just downstream of The Billabong, flood waters pass through/across the Park St bridge and combine with flow travelling down the Gloucester River. Flow rates for the Gloucester River at Gloucester gauge location are presented in Table 8-4 (Section 8.2.3). Flow through The Billabong makes up approximately 25% of flow recorded at the gauge for the 10% AEP event. For the 1% AEP event, approximately 50% of the flow modelled at the Gloucester River at Gloucester gauge flows through The Billabong across Denison Street. As flood events get larger beyond the 1% AEP, The Billabong conveys a larger proportion of flow than the Gloucester River channel and its immediate floodplain area.

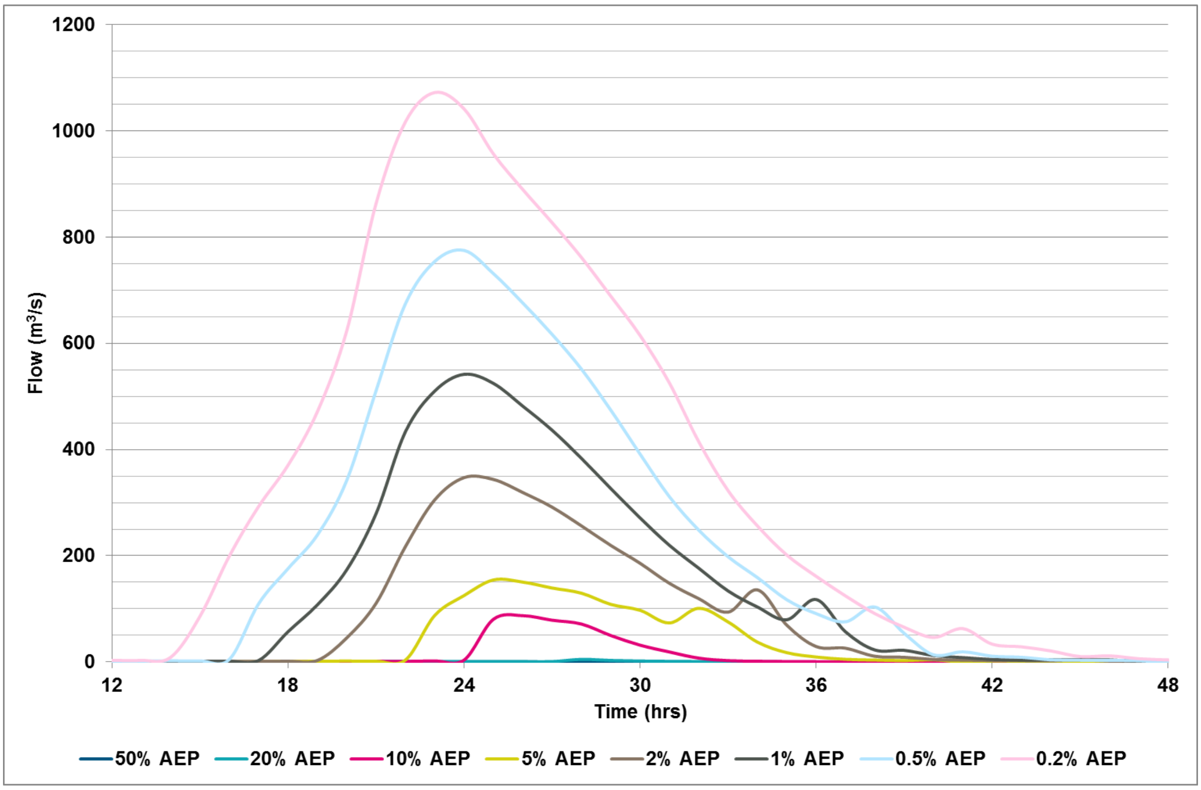


Figure 8-4 Modelled Design Event Hydrographs for The Billabong

8.2 Broader Catchment

8.2.1 Flood Behaviour

Flooding within the Barrington River catchment is characterised by deep and rapidly rising floodwaters. The Barrington River floodplain is broad (approximately 300-500m wide, reaching up to 1km in locations downstream near Barrington) and well-defined, with steep valley sides. The channel is wide and deep and has considerable flow conveyance capacity. For the modelled design events, the initial response of rising floodwaters occurs approximately 8 hours after the onset of rainfall. Flow through some sections of the Barrington River remain entirely in-channel up to the 2% AEP event, with velocities through the channel reaching above 5m/s. The deep, fast flow of floodwaters through the Barrington River pose a significant flood hazard, particularly to vehicle crossings.

Flooding in the Gloucester River is characterised by an extensive network of flood runners through the floodplain. Floodplain inundation first occurs during the 20% AEP event, however extensive floodplain inundation is not observed until the 5% AEP and 2% AEP. Typical depths of floodwaters throughout the floodplain are within the order of 0.5-1m. However, the depth of floodwater through the Gloucester River channel downstream of the Barrington River confluence reaches around 13-15m during the 1% AEP event. Floodplain inundation occurs around 15 hours after the onset of rainfall for the 1% AEP event. The flood behaviour into Town through The Billabong was detailed in Section 8.1.1.

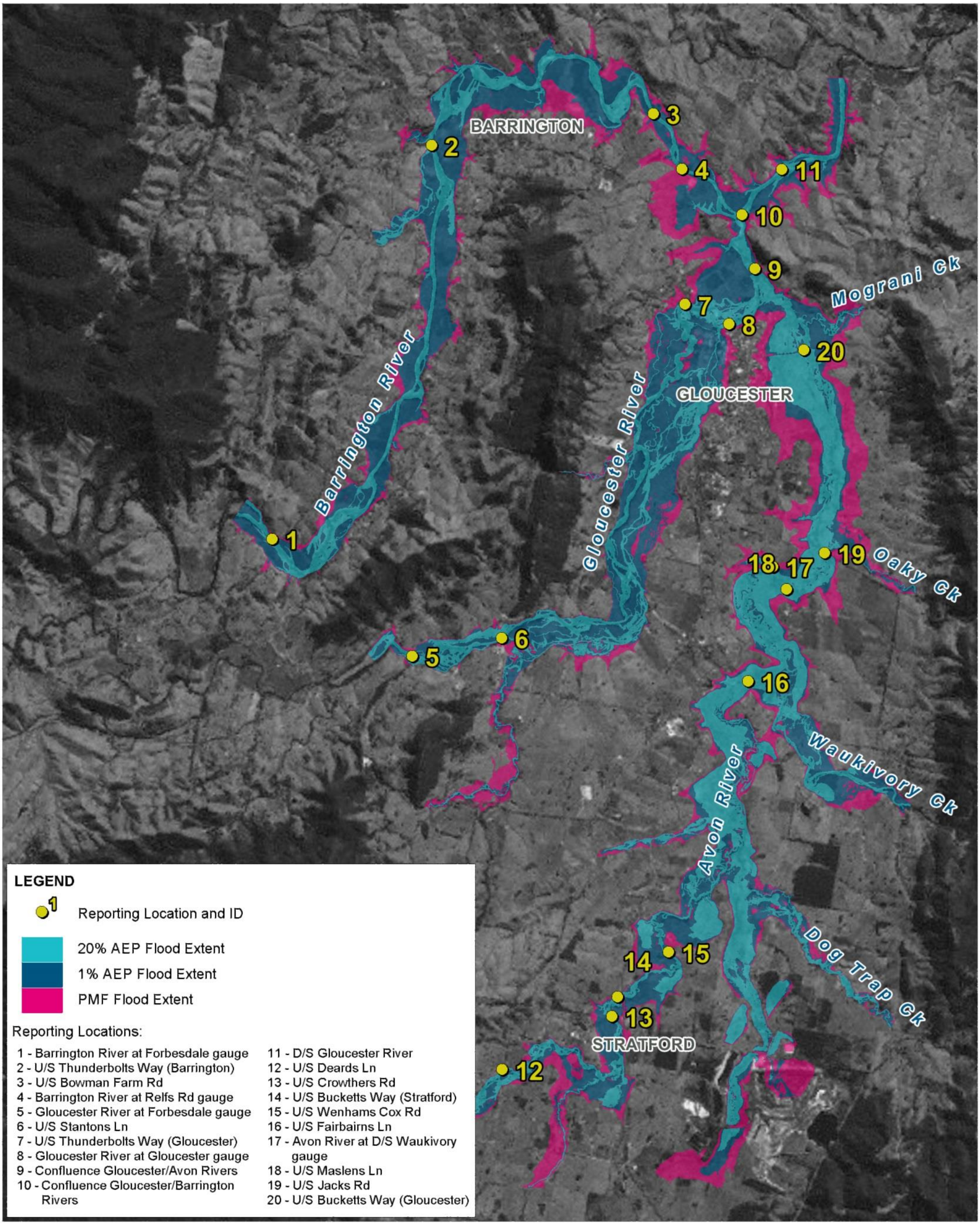
The Avon River is often perched above the floodplain. When the rate of flow exceeds channel capacity, it spills onto the floodplain. The in-channel capacity of the Avon River is breached during the 50% AEP event and significant floodplain inundation occurs. Initially, floodwater rises at a much slower rate compared to the other two catchments, however the onset of floodplain inundation occurs at a similar time to that of the Gloucester River (at around 15 hours after the onset of rainfall in a 48-hour duration design event). Areas of the floodplain can remain inundated for days after the peak of the event is reached. Typical depths of inundation across the Avon River floodplain are within the order of 1-1.5m during the 10% AEP event and 2-3m during the 1% AEP event.

Throughout the three catchments, the majority of properties in the broader catchment area are situated at or beyond the edge of inundation. There are only a few properties that become inundated during the PMF event.

8.2.2 Peak Flood Conditions

Modelled peak flood levels at selected locations (as presented in Figure 8-5) are shown in Table 8-3, for the full range of design flood events considered.

Longitudinal profiles showing modelled peak flood levels for the Gloucester River and Avon River are shown in Figure 8-6 and Figure 8-7 respectively, with the channel bed profile also shown for reference. The flood level profile for the Barrington River is presented in Figure 8-8.



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Design Flood Inundation Extents and Reporting Locations Broader Catchment

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Table 8-3 Modelled Peak Flood Levels (m AHD) for Design Flood Events, Broader Catchment

ID	Reporting Location	Flood Event Frequency								
		50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
1	Barrington River at Forbesdale gauge	127.6	128.8	129.7	130.3	131.1	131.6	132.2	132.9	134.9
2	U/S Thunderbolts Way (Barrington)	105.0	106.6	107.6	108.3	108.9	109.3	109.7	110.3	112.5
3	U/S Bowman Farm Rd	89.8	91.4	92.6	93.7	95.5	96.8	98.4	99.6	103.4
4	Barrington River at Relfs Rd gauge	87.0	88.7	90.0	91.0	92.8	94.0	95.1	96.7	102.2
5	Gloucester River at Forbesdale gauge	126.7	127.4	127.7	127.9	128.2	128.5	128.8	129.2	130.6
6	U/S Stantons Ln	119.9	120.4	120.8	121.1	121.4	121.7	122.1	122.5	123.9
7	U/S Thunderbolts Way (Gloucester)	91.9	92.5	92.8	93.0	93.3	93.6	94.5	96.4	102.4
8	Gloucester River at Gloucester gauge	89.1	89.8	90.2	90.5	91.7	93.0	94.5	96.4	102.4
9	Confluence Gloucester/Avon Rivers	85.6	87.2	88.6	89.4	91.5	93.0	94.4	96.4	102.4
10	Confluence Gloucester/Barrington Rivers	84.1	86.1	87.7	88.7	90.9	92.4	93.9	95.9	101.9
11	D/S Gloucester River	82.1	84.0	85.9	87.2	89.8	91.4	92.9	95.0	100.9
12	U/S Deards Ln	130.3	130.5	130.7	130.8	131.0	131.1	131.2	131.5	132.2
13	U/S Crowthers Rd	116.6	117.4	117.9	118.0	118.5	118.8	119.2	119.9	121.1
14	U/S Bucketts Way (Stratford)	115.7	116.5	117.0	117.3	118.0	118.5	119.0	119.7	120.9
15	U/S Wenhams Cox Rd	111.8	112.8	113.4	113.7	113.9	114.0	114.1	114.3	114.9
16	U/S Fairbairns Ln	100.5	100.9	101.2	101.3	101.9	102.2	102.5	102.9	104.6
17	Avon River at DS Waukivory gauge	96.5	96.7	96.9	97.0	97.6	97.9	98.2	98.7	102.7
18	U/S Maslens Ln	96.1	96.4	96.6	96.7	97.2	97.5	97.8	98.2	102.6
19	U/S Jacks Rd	94.6	94.8	95.0	95.1	95.8	96.1	96.5	97.3	102.5
20	U/S Bucketts Way (Gloucester)	89.2	89.6	89.9	90.1	91.8	93.2	94.6	96.5	102.4

The lower reach of the Gloucester River is influenced by coincident flood conditions in the Avon and Barrington Rivers. The extent of backwater inundation can be seen in Figure 8-6.For the 1% AEP, the backwater inundation can be observed up to Thunderbolts Way.

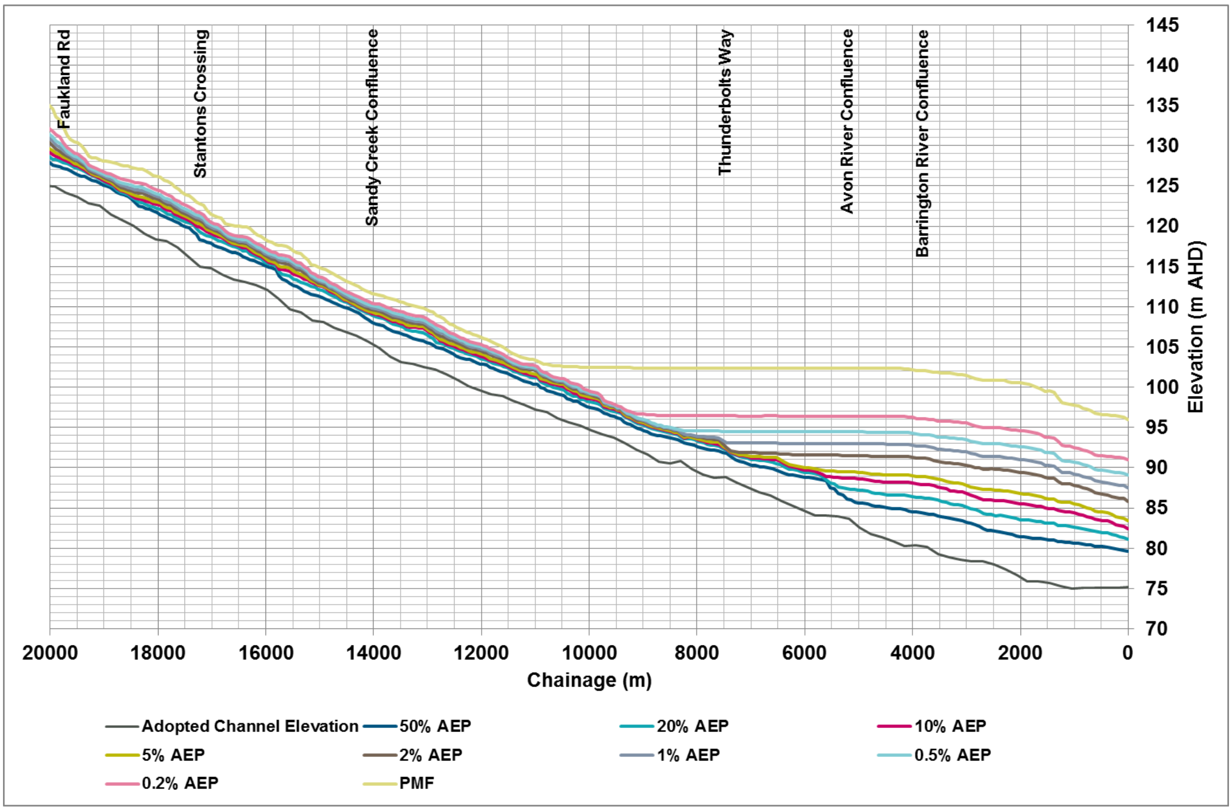


Figure 8-6 Gloucester River Design Peak Flood Level Profiles

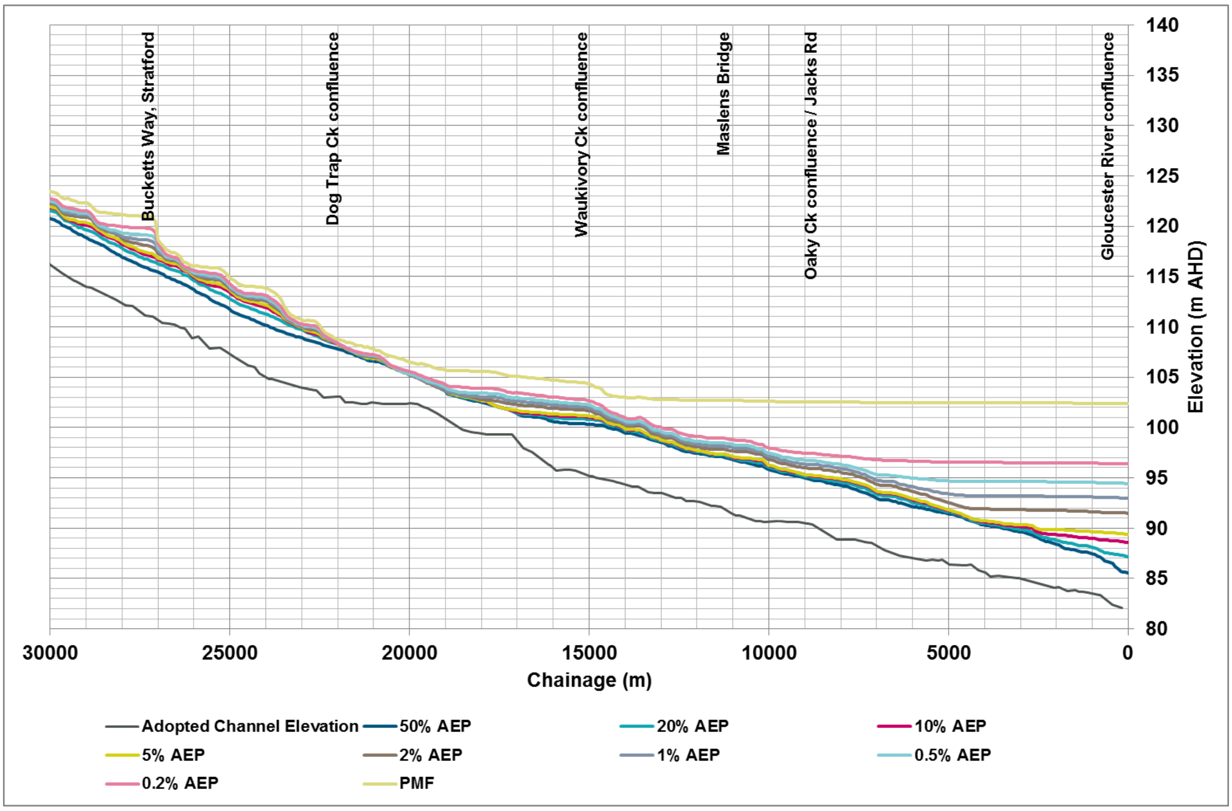


Figure 8-7 Avon River Design Peak Flood Level Profiles

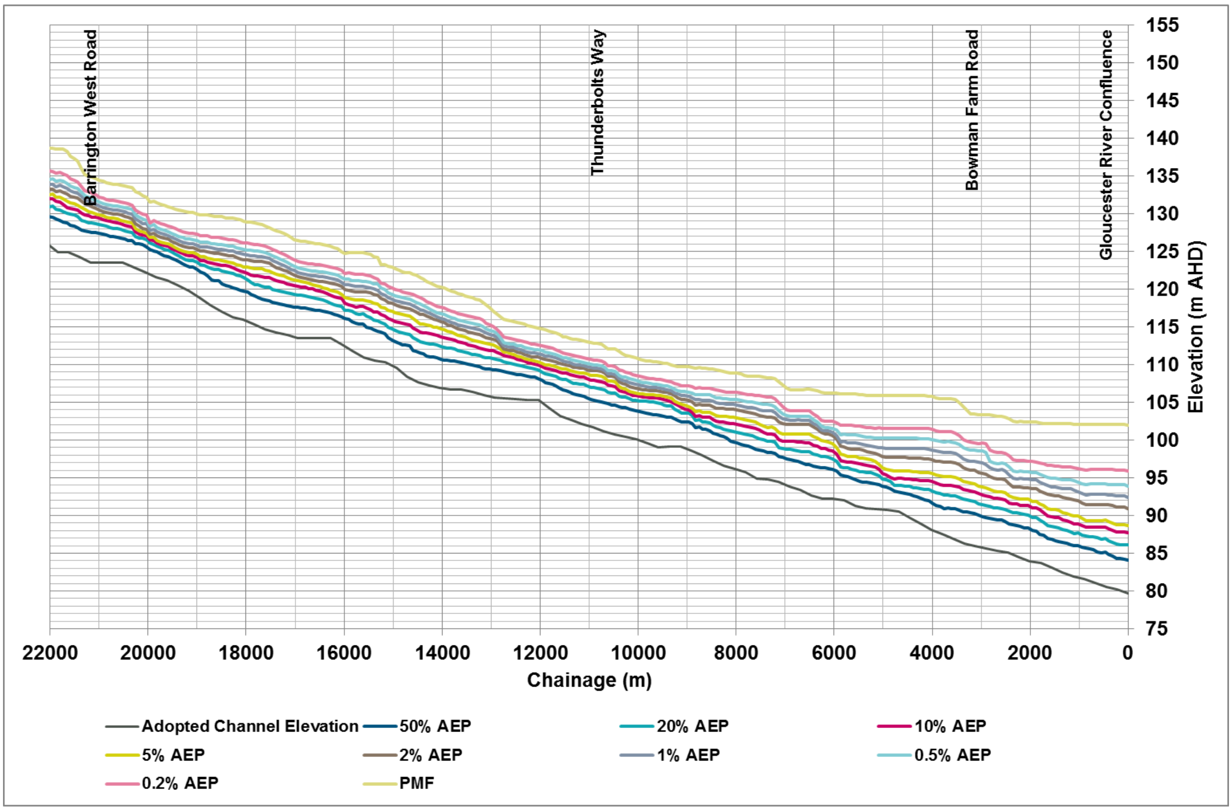


Figure 8-8 Barrington River Design Peak Flood Level Profiles

8.2.3 Flood Flows

Modelled peak flood flows at selected locations are shown in Table 8-4 for the full range of design flood events considered. The modelled flood hydrographs located downstream on each of the three river systems is presented in Figure 8-9. It shows the modelled flood hydrographs on each major river just upstream of the confluence area, together with the combined flow downstream for the 1% AEP event.

The same temporal pattern was applied across each of the catchments and results in slightly staggered timing of the peak flow on each river system. The travel time of the flood wave through the catchment is influenced by factors including slope of terrain, topographic controls and model parameters. For the 1% AEP, presented in Figure 8-9, the Gloucester River peaks first, around 24 hours after design rainfall is applied to the model. The Barrington River peaks around 4 hours later.

The flow through the Avon River is more attenuated due to the nature of the floodplain, with the peak flow occurring just before 30 hours. The magnitude of flow in each river system is roughly proportional to the size of the catchment. The design flows in each catchment remain in close enough succession that the peak flow downstream of the Barrington River confluence is essentially a combined total of the three. Modelled design flow hydrographs for the Gloucester River at Forbesdale, Avon River at D/S Waukivory and Barrington River at Forbesdale gauges are presented in Figure 8-10 to Figure 8-12 respectively. The nature of the Avon River floodplain attenuation is evident, with the timing of the peak flow becoming progressively earlier with increasing event magnitude, particularly noticeable between the 5% AEP and 2% AEP events.

Table 8-4 Modelled Peak Flows (m^3/s) for Design Flood Events, Broader Catchment

Location	Flood Event Frequency								
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
Barrington River at Forbesdale gauge	250	530	800	1110	1700	2310	3020	4120	8790
Barrington River at Relfs Rd gauge	290	600	890	1200	1890	2550	3330	4550	9430
Gloucester River at Forbesdale gauge	110	200	290	400	610	810	1050	1460	3240
Gloucester River at Gloucester gauge	140	240	360	480	740	960	1210	1580	3150
Gloucester River D/S Barrington River confluence	460	900	1460	1900	3150	4220	5470	7440	15300
Waukivory Creek U/S Avon River confluence	40	70	110	120	230	310	400	550	1440
Avon River at D/S Waukivory gauge	90	180	260	300	630	880	1140	1570	3390
Avon River U/S Gloucester River confluence	80	190	280	330	660	870	1110	1500	2770

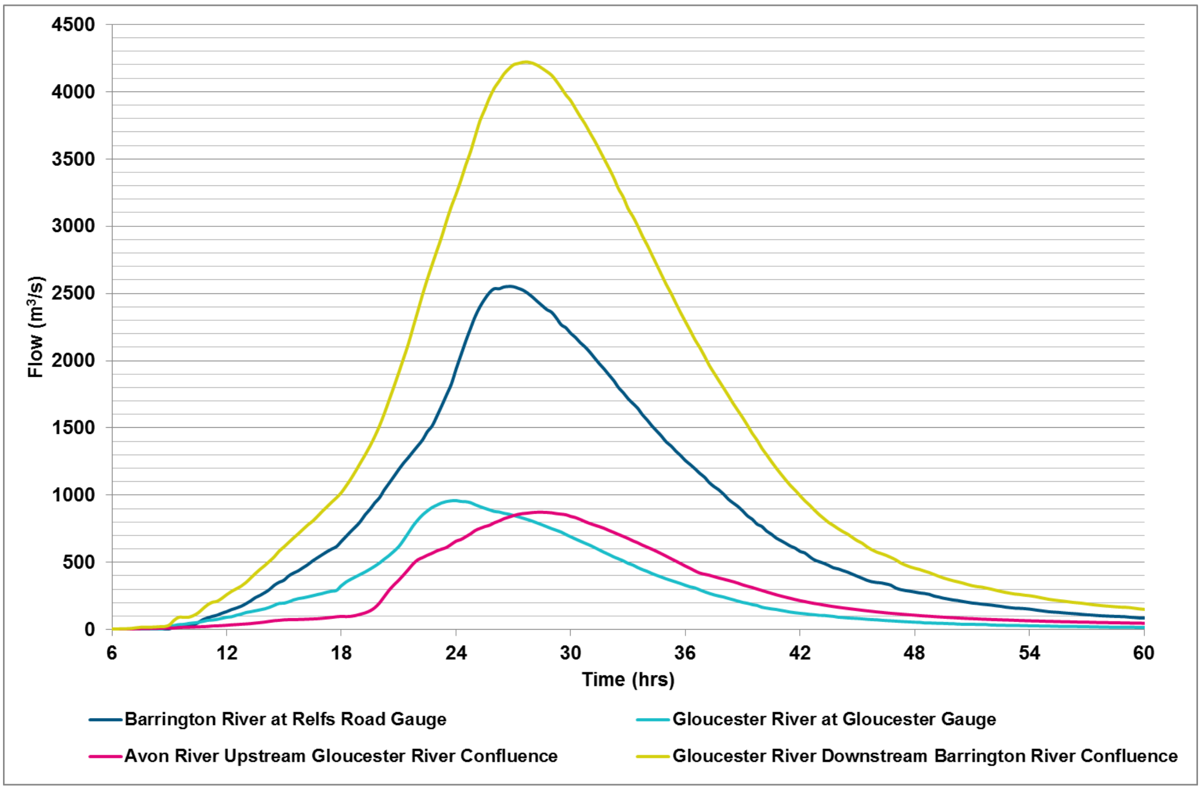


Figure 8-9 Modelled 1% AEP Hydrographs at Selected Locations

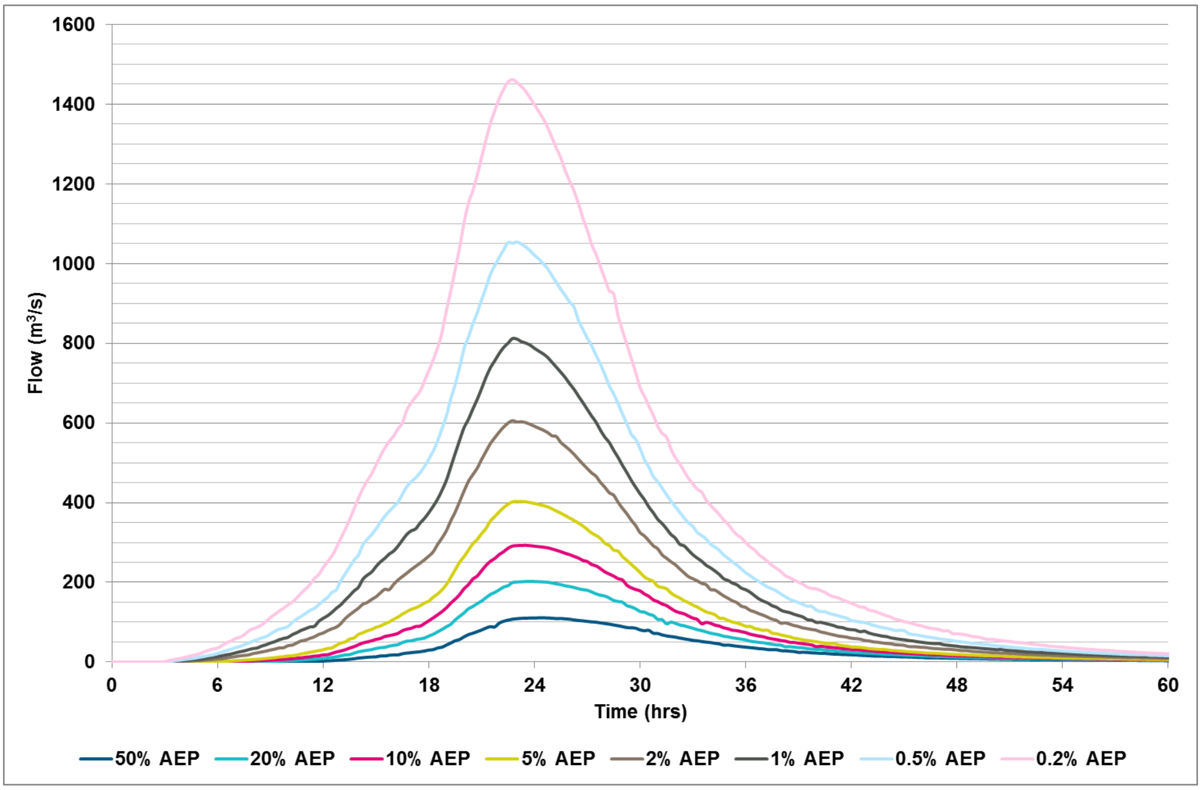


Figure 8-10 Modelled Design Event Hydrographs for the Gloucester River at Forbesdale

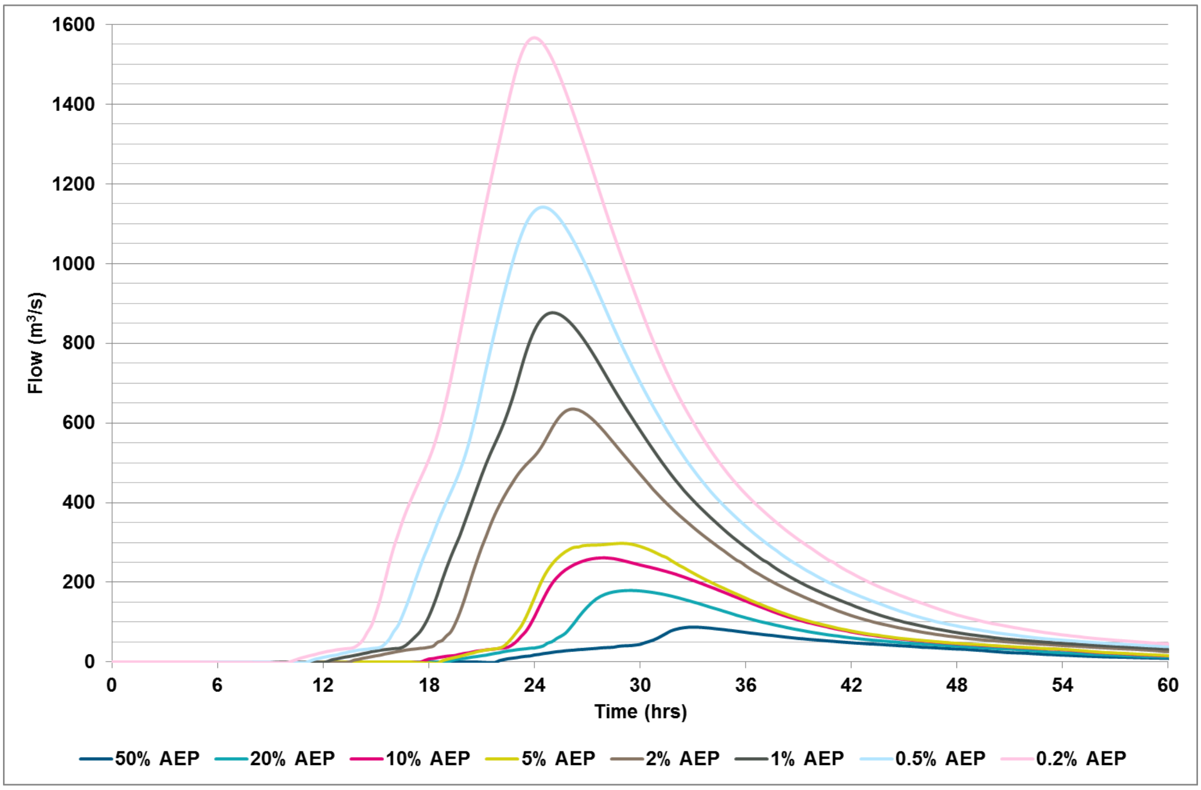


Figure 8-11 Modelled Design Event Hydrographs for the Avon River at D/S Waukivory

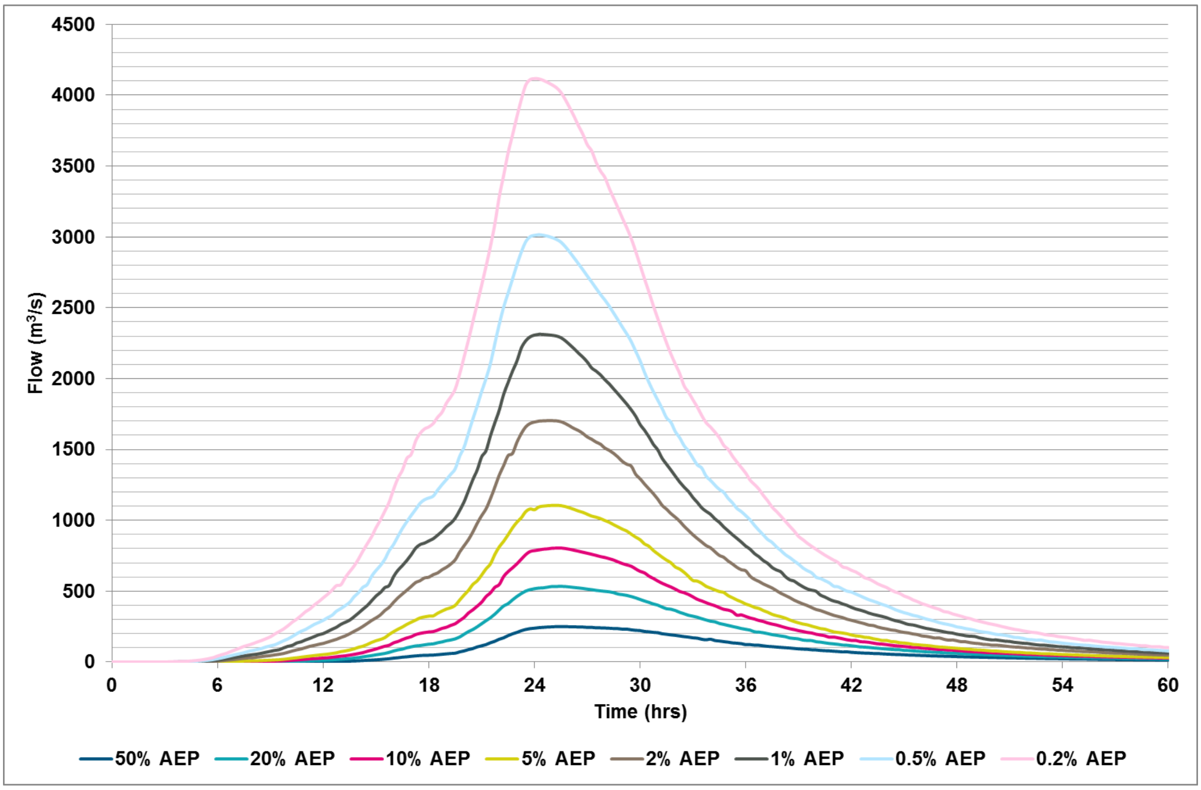


Figure 8-12 Modelled Design Event Hydrographs for the Barrington River at Forbesdale

8.3 Coincident Flood Conditions

The impact of different flood conditions occurring in each of the catchments was investigated through a number of sensitivity tests. This consisted of a total of nine scenarios representing:

- A 5% AEP flood condition in each individual catchment coincident with a 20% AEP flood condition in the other two catchments;
- A 1% AEP flood condition in each individual catchment coincident with a 5% AEP flood condition in the other two catchments; and
- A 0.2% AEP flood condition in each individual catchment coincident with a 1% AEP flood condition in the other two catchments.

8.3.1 Impact of Coincident Flooding at Gloucester

The peak flood level surface has been extracted from the model results for each of the coincident flooding scenarios, i.e. a coincident design flooding condition in all three catchments and the design flood condition in each individual catchment with lower flood conditions in the other two. The peak flood level profiles along the Gloucester River from the Barrington River to The Billabong and then extended upstream along The Billabong are presented in Figure 8-13 to Figure 8-15.

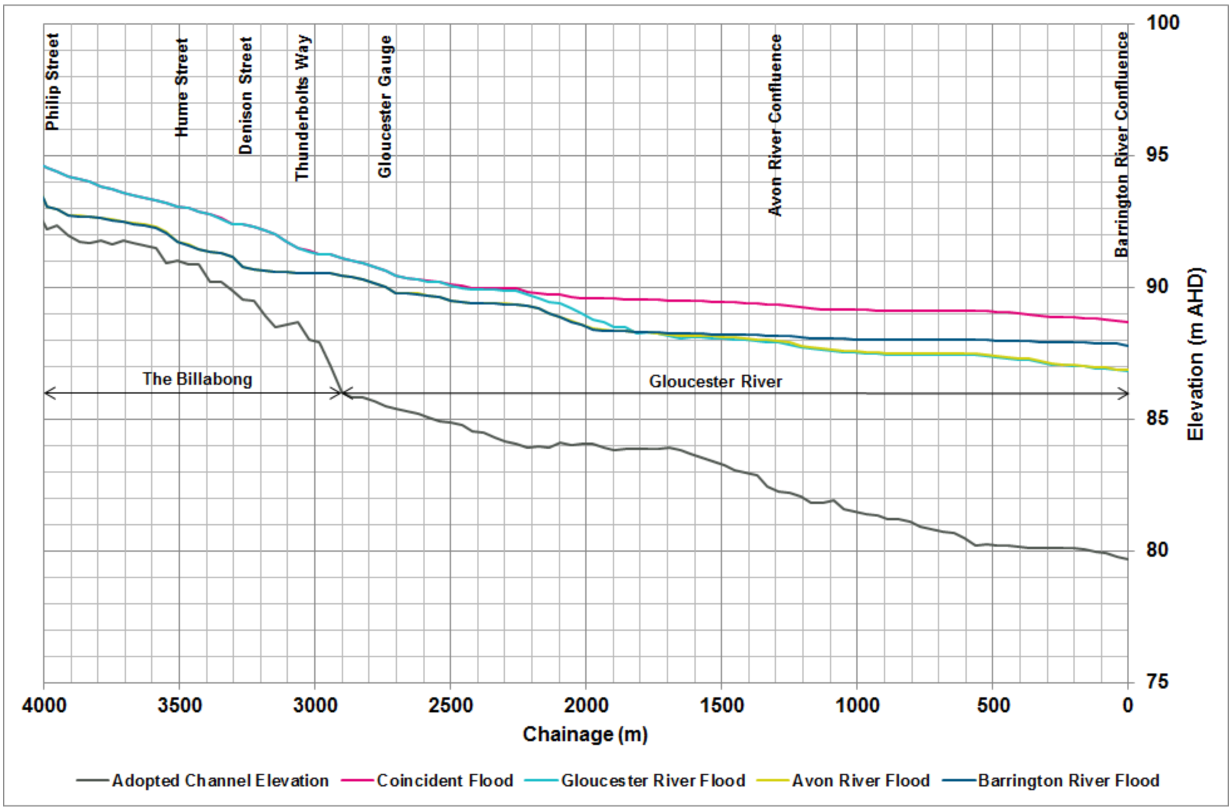


Figure 8-13 Impact of Coincident Flooding Conditions at Gloucester for the 5% AEP Event

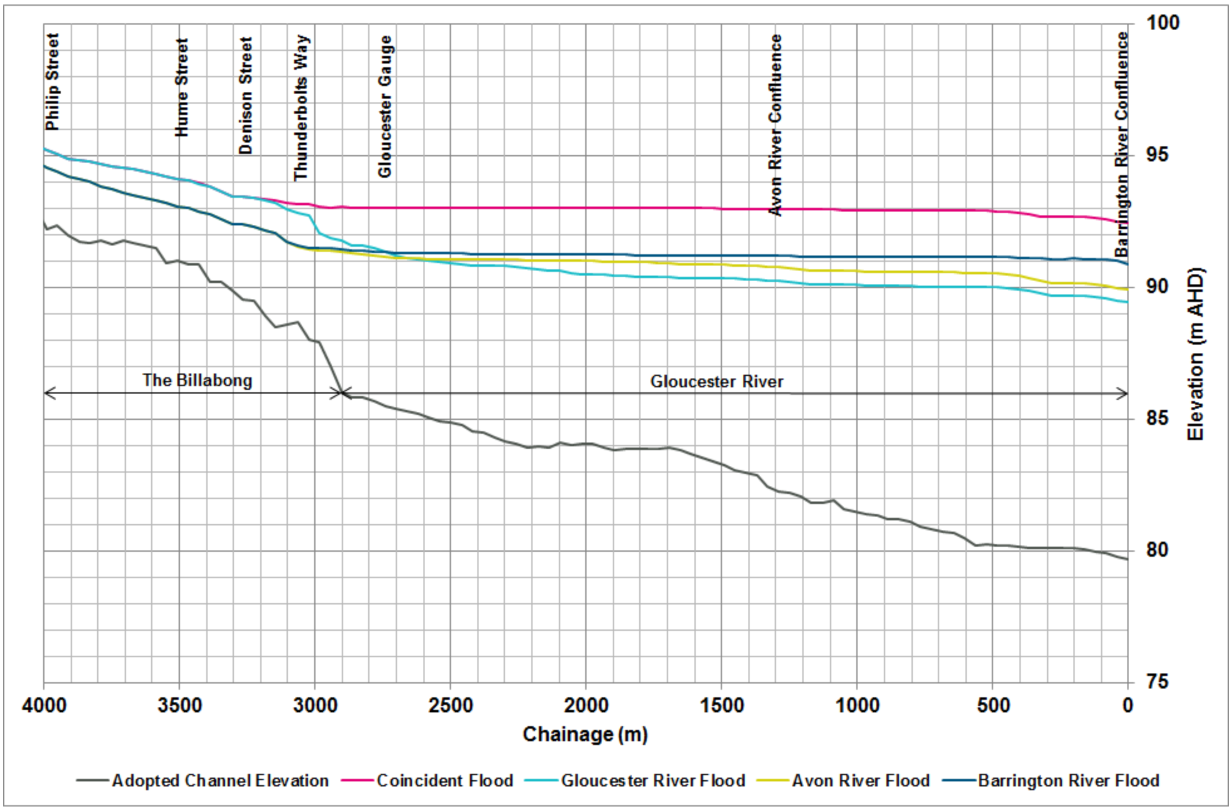


Figure 8-14 Impact of Coincident Flooding Conditions at Gloucester for the 1% AEP Event

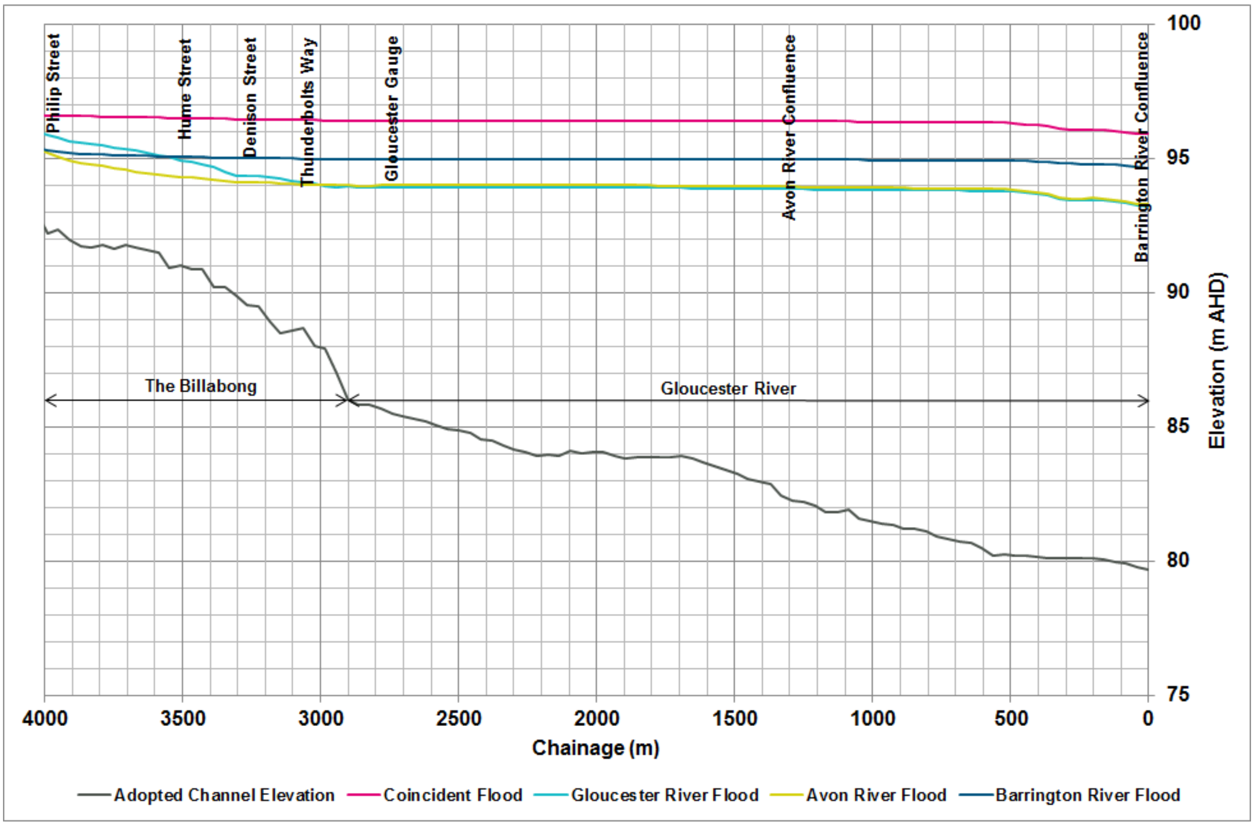


Figure 8-15 Impact of Coincident Flooding Conditions at Gloucester for the 0.2% AEP Event

For the 5% AEP event it can be seen that the influence of the coincident flooding conditions on the Gloucester, Avon and Barrington Rivers is restricted to the area around the confluences. It does not extend upstream along the Gloucester River as far as the Gloucester gauge. The flooding condition along The Billabong is driven by the Gloucester River and is independent of the flows in the Avon and Barrington Rivers at this design magnitude.

For flood events of a 1% AEP magnitude the influence of the coincident flood conditions extends further upstream, impacting on flood levels at the Gloucester gauge and the downstream reaches of The Billabong (although not upstream to Denison Street). A 1% AEP flood condition on any individual catchment (coincident with a 5% AEP condition on the other two) will produce a similar flood level at the Gloucester gauge, with a coincident 1% AEP flood across all three catchments producing a peak flood level over 1.5m higher.

For flood events of a 0.2% AEP magnitude the influence of the coincident flood conditions extends through Gloucester along the entire length of The Billabong. A 0.2% AEP flood condition on either the Gloucester River or Avon River (coincident with a 1% AEP condition on the other two) will produce a similar flood level at the Gloucester gauge, with a 0.2% AEP flood in the Barrington River producing a peak flood level around 1m higher. A coincident 0.2% AEP flood across all three catchments increases the peak flood level by almost 1.5m further. At this magnitude the Barrington River is the critical driver for flood levels downstream of Hume Street and the Gloucester River for flood levels upstream of Hume Street. A coincident 0.2% AEP flood across all three catchments increases the peak flood level along The Billabong by around 1m or more.

8.3.2 Extent of Coincident Flooding Influence

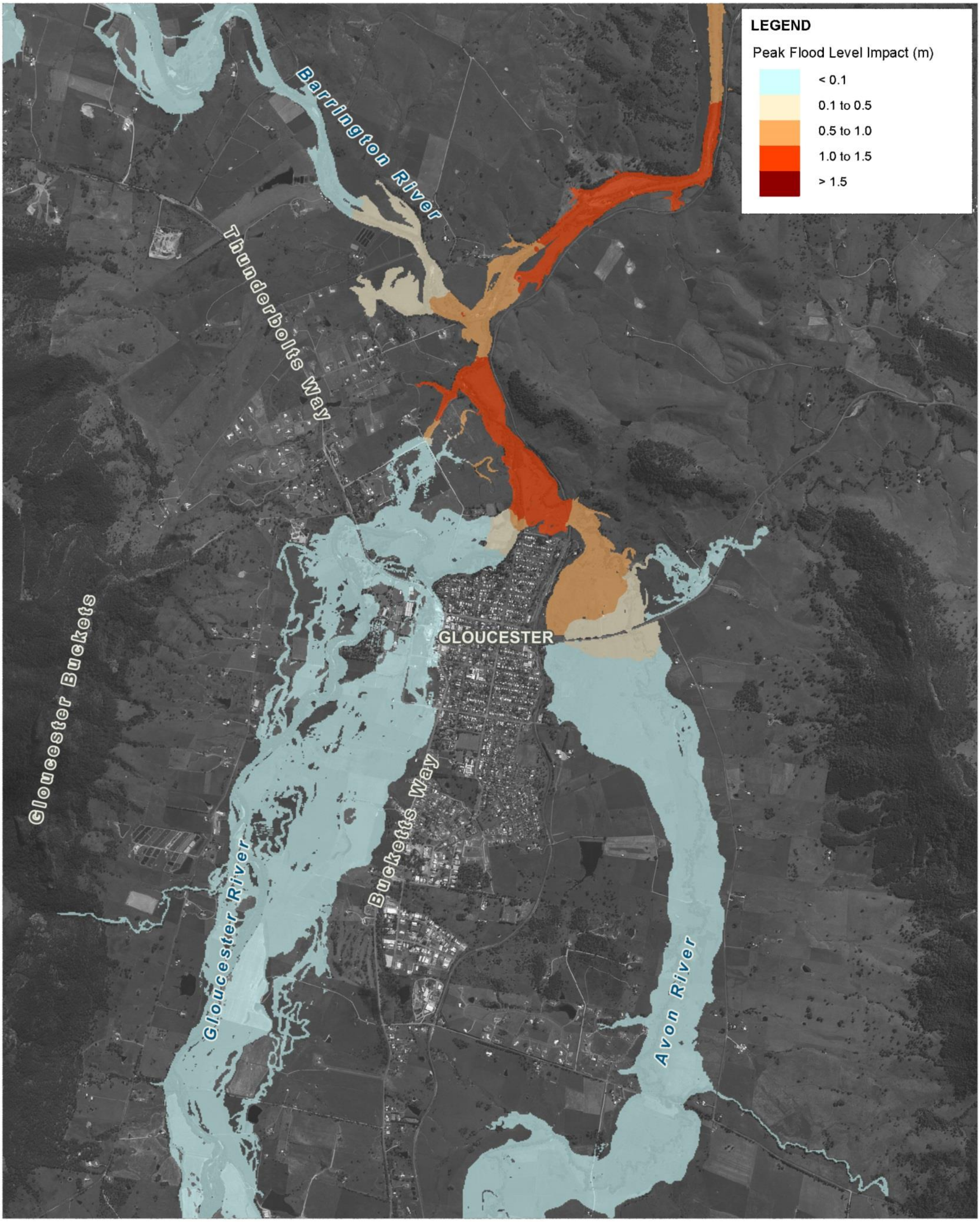
The peak flood level profiles presented in Figure 8-13 to Figure 8-15 provide some spatial context to the influence of the coincident flood conditions along the Gloucester River and Billabong, but this is demonstrated more comprehensively through flood level impact mapping, as presented in Figure 8-16 to Figure 8-18.

These maps demonstrate the extent of the coincident flood conditions on the modelled peak flood levels. In each case they present the difference between the flood levels from the baseline design condition (similar magnitude event occurring coincidently across all three catchments) to those of the sensitivity tests (the design flood magnitude occurring in each individual catchment with lower flood conditions in the other two). The peak flood surfaces of the sensitivity tests have been combined to produce the maximum flood levels modelled from each of the three conditions (dominant flooding on the Gloucester River, Avon River or Barrington River).

For the 5% AEP event it can be seen that upstream of the Barrington River confluence the impact of the coincident flood conditions is greatest upstream to the Avon River confluence. Along the Gloucester River the influence quickly diminishes prior to the location of the Gloucester gauge. The influence of the coincident flood condition is more pronounced on the Avon River, extending upstream to around the location of the Bucketts Way. The impact along the Barrington River is fairly well confined to the lower 1.5km reach, extending upstream to around the location of the Relfs Road gauge.

For the 1% AEP event the influence of the coincident flood conditions is significant throughout the lower reaches of the Gloucester and Avon Rivers, to around the Gloucester gauge and Bucketts Way respectively. On the Gloucester River the coincident flooding influence reduces upstream of the gauge, becoming insignificant upstream of the Thunderbolts Way. However, there is some impact along The Billabong upstream to Queen Street. On the Avon River the coincident flooding influence reduces upstream of the Bucketts Way, becoming insignificant around halfway between there and Jacks Road. The impact along the Barrington River is fairly well confined to the lower 2.5km reach.

For the 0.2% AEP event the influence of the coincident flood conditions is significant throughout the lower reaches of the Gloucester and Avon Rivers, including within Gloucester itself. On the Gloucester River and The Billabong the impact extends to around the alignment of Philip Street before quickly diminishing. Along the Avon River the extent of the coincident flooding influence is significant to around the Oaky Creek confluence, then gradually reducing upstream, almost as far as Maslens Lane. The impact along the Barrington River is fairly well confined to the lower 3.0km reach.



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Extent of Coincident Flooding Influence for the 5% AEP Event

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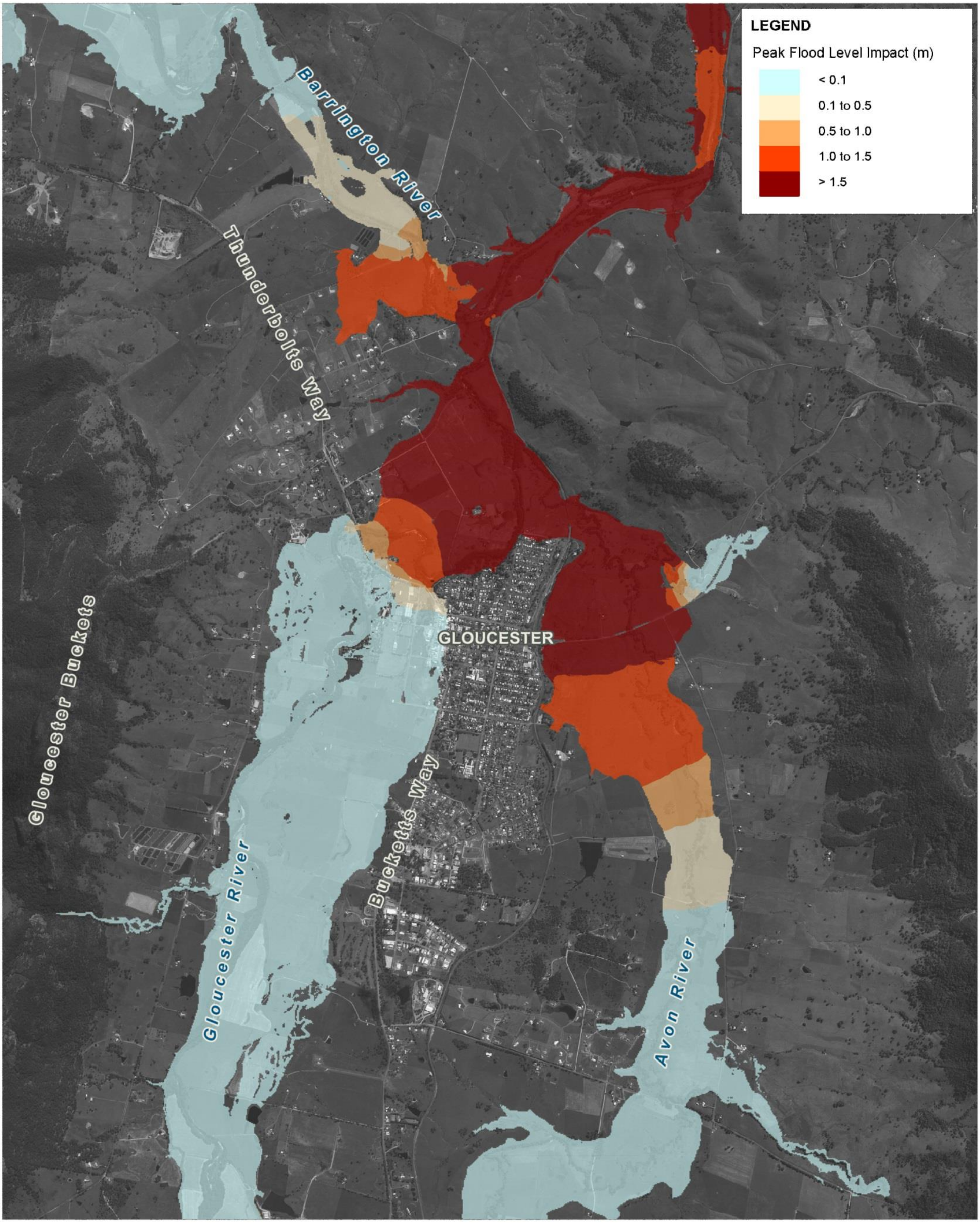

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Extent of Coincident Flooding Influence for the 1% AEP Event

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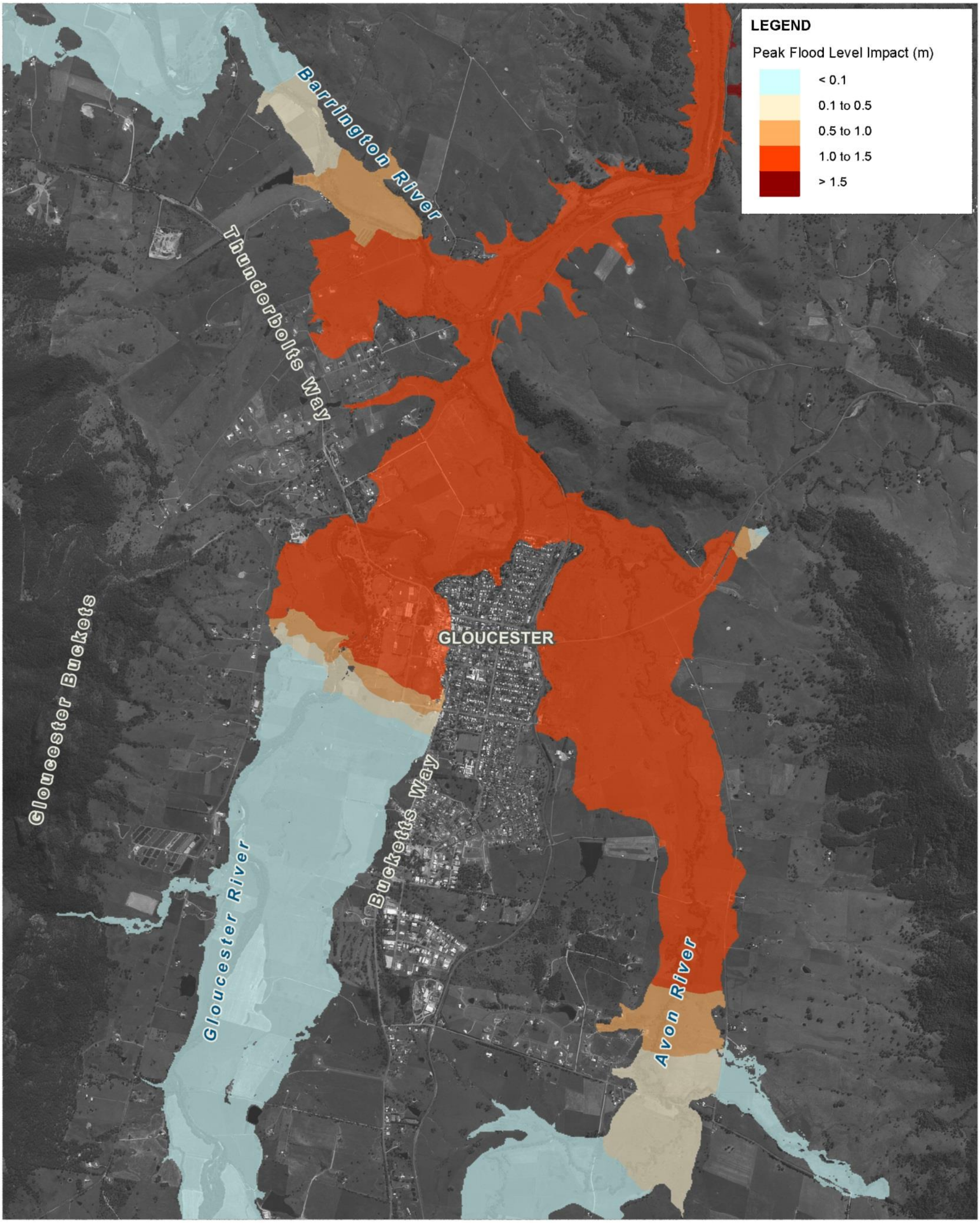

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Extent of Coincident Flooding Influence for the 0.2% AEP Event

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8.4 Hydraulic Categorisation

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the NSW Floodplain Development Manual (DIPNR, 2005) are essentially qualitative in nature. Of particular difficulty is the fact that a definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment.

The hydraulic categories as defined in the Floodplain Development Manual are:

- **Floodway -** Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage -** Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.
- **Flood Fringe -** Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

A number of approaches were considered when attempting to define flood impact categories across the study catchment. The approach that was adopted derived a preliminary floodway extent from the velocity * depth product (sometimes referred to as unit discharge). The peak flood depth was used to define flood storage areas. The adopted hydraulic categorisation is defined in Table 8-5.

Table 8-5 Hydraulic Categories

Floodway	Velocity * Depth > 0.3 at the 1% AEP event	Areas and flowpaths where a significant proportion of floodwaters are conveyed (including all bank-to-bank creek sections).
Flood Storage	Velocity * Depth < 0.3 and Depth > 0.5 metres at the 1% AEP event	Areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	Flood extent of the PMF event	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

Preliminary hydraulic category mapping is included in the Mapping Compendium, and is presented for the 10% AEP, 5% AEP, 2% AEP and 1% AEP events.

For the 1% AEP event, the floodway area is extensive in all three river systems. Most of the floodplain is classed as floodway. Small areas of the Gloucester River floodplain around Gloucester town do not experience as severe flooding and are classes as flood fringe. There are almost no areas of flood storage within the study area, with the exception of isolated sections along the Avon River floodplain.

8.5 Provisional Hazard

The NSW Floodplain Development Manual (DIPNR, 2005) defines flood hazard categories as follows:

- **High hazard** – possible danger to personal safety; evacuation by trucks is difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings; and
- **Low hazard** – should it be necessary, trucks could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

The key factors influencing flood hazard or risk are:

- Size of the Flood
- Rate of Rise - Effective Warning Time
- Community Awareness
- Flood Depth and Velocity
- Duration of Inundation
- Obstructions to Flow
- Access and Evacuation

The provisional flood hazard level is often determined on the basis of the predicted flood depth and velocity. This is conveniently done through the analysis of flood model results. A high flood depth will cause a hazardous situation while a low depth may only cause an inconvenience. High flood velocities are dangerous and may cause structural damage while low velocities generally have no major threat.

Figures L1 and L2 in the Floodplain Development Manual are used to determine provisional hazard categorisations within flood liable land. These figures are reproduced in Figure 8-19. The provisional hydraulic hazard is included as mapping series H of the Mapping Compendium and is based on the 1% AEP design event.

Provisional hazard category mapping is included in the Mapping Compendium, and is presented for the 10% AEP, 5% AEP, 2% AEP and 1% AEP events.

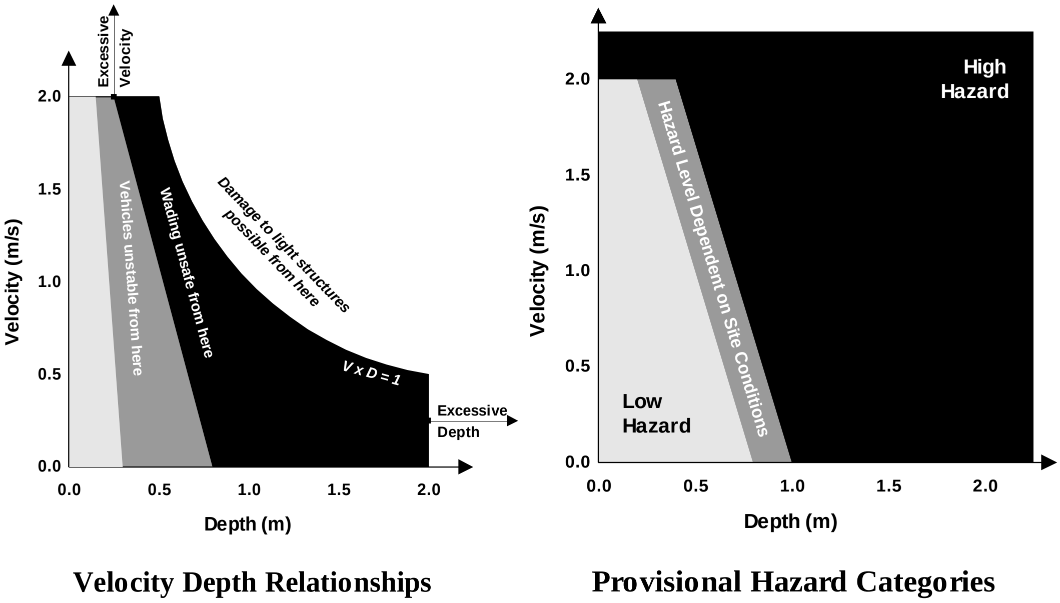


Figure 8-19 Provisional Flood Hazard Categorisation

8.6 Sensitivity Tests

8.6.1 Climate Change

The potential impacts of future climate change were considered for the 1% AEP design event. The projected increases in rainfall intensities expected for the study area and the approach adopted to incorporate these into the modelling is detailed in 7.6. Longitudinal profiles showing the impacts of potential future climate change for the Gloucester River and Avon River are shown in Figure 8-20 and Figure 8-21, respectively. The Barrington River profile is presented in Figure 8-22. Peak modelled flood levels are presented in Table 8-9 at the end of this Section.

8.6.2 Channel and Floodplain Roughness

The sensitivity of modelled peak flood levels to the adopted Manning's 'n' roughness values were tested for the 1% AEP design event. Roughness values for all materials types within the channel and floodplain were increased and decreased by 25%. Longitudinal profiles showing the result of this assessment for the Gloucester River and Avon River are shown in Figure 8-23 and Figure 8-24, respectively. The Barrington River profile is presented in Figure 8-25. Peak modelled flood levels are presented in Table 8-9 at the end of this Section.

8.6.3 Channel Bed Level

Given the approach adopted to derive channel bed elevations (as discussed in Section 4), sensitivity tests of the peak flood level results was undertaken for changes in the channel bed elevation. To determine the impact of raising the bed elevation on the modelled peak flood levels for the 1% AEP design event, the raw LiDAR bed elevation was adopted as it is representative of the highest possible bed elevation. To simulate the scenario where the actual channel bed is lower than the modelled channel bed, the adopted channel was lowered an additional 0.5m.

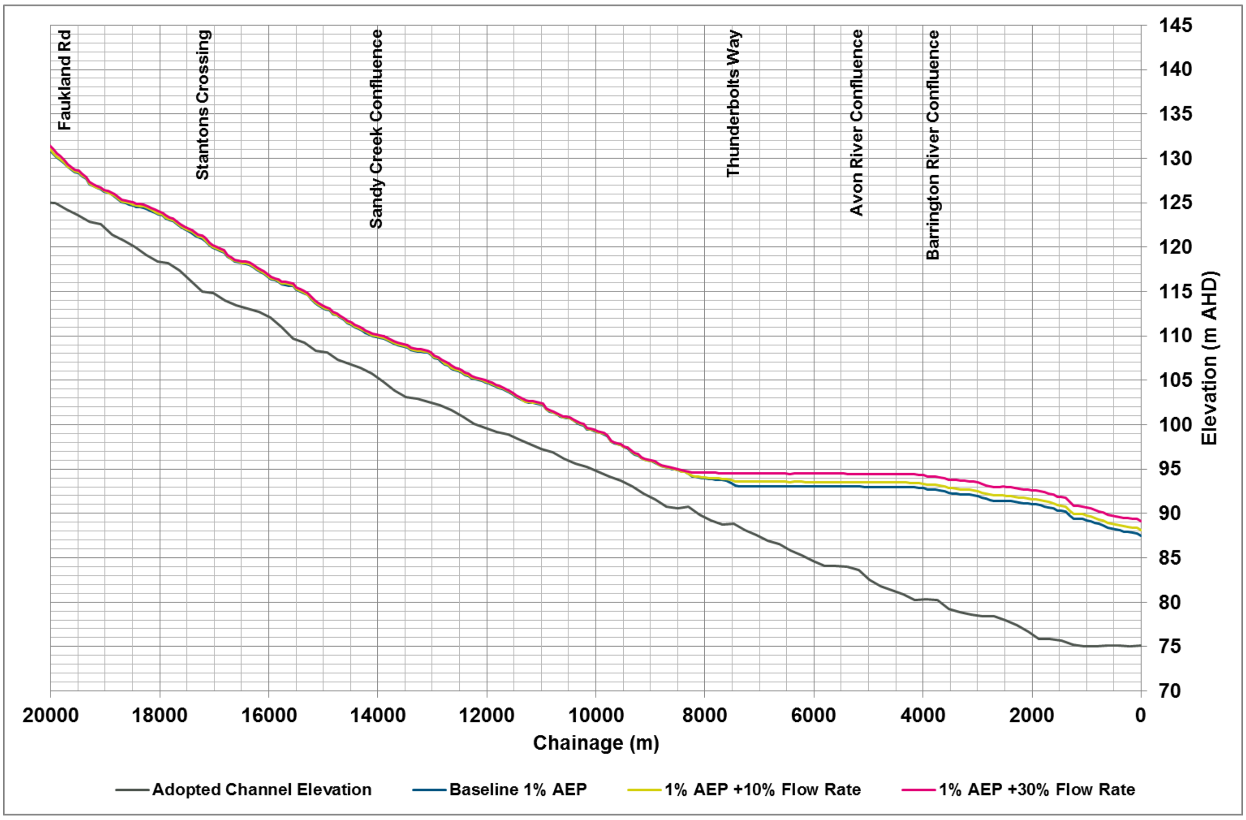


Figure 8-20 Gloucester River Climate Change Scenarios Peak Flood Level Profiles

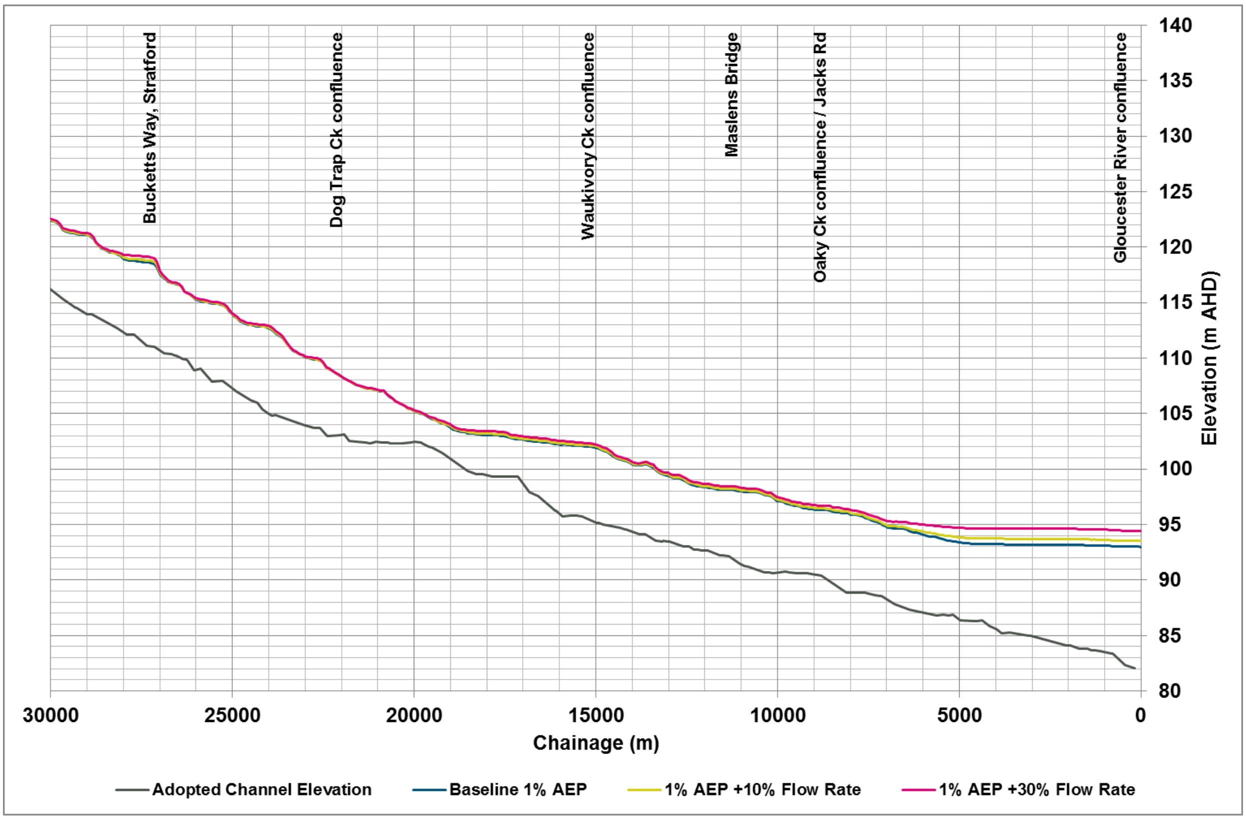


Figure 8-21 Avon River Climate Change Scenarios Peak Flood Level Profiles

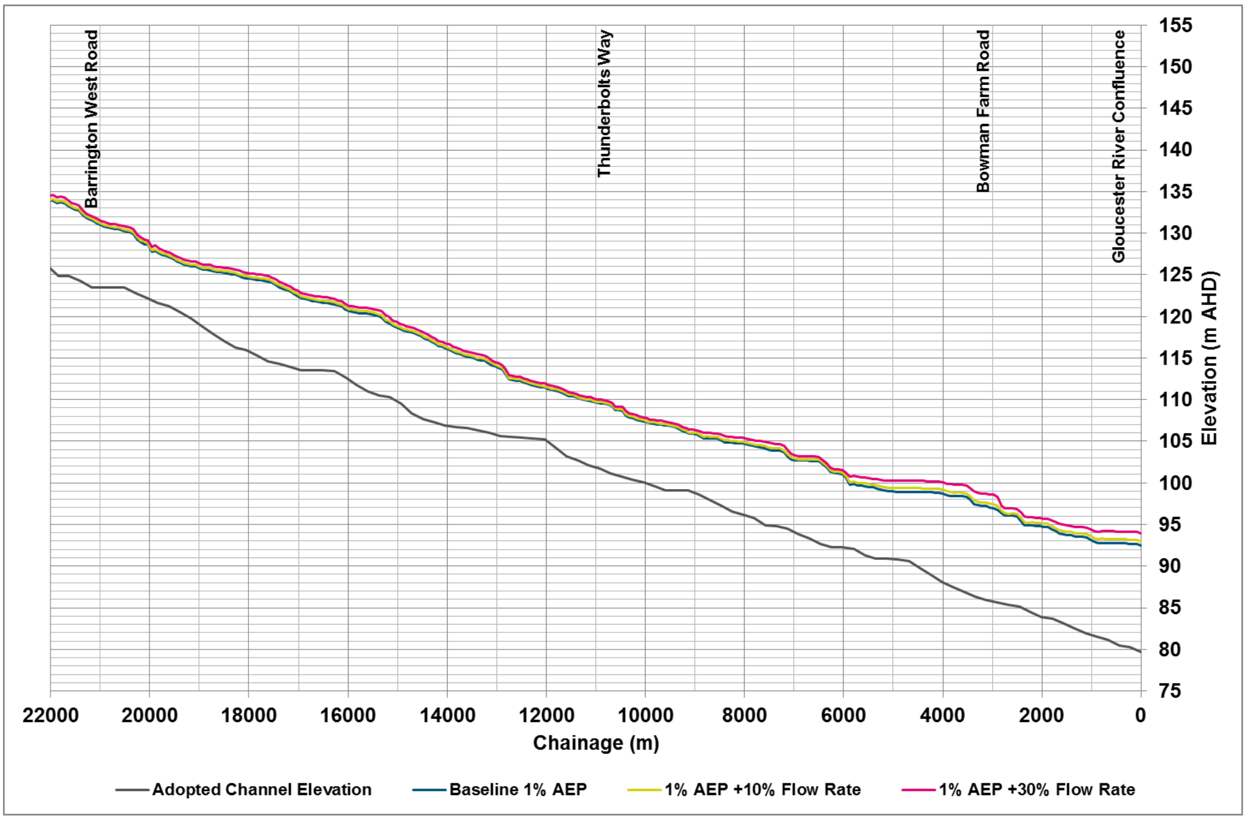


Figure 8-22 Barrington River Climate Change Scenarios Peak Flood Level Profiles

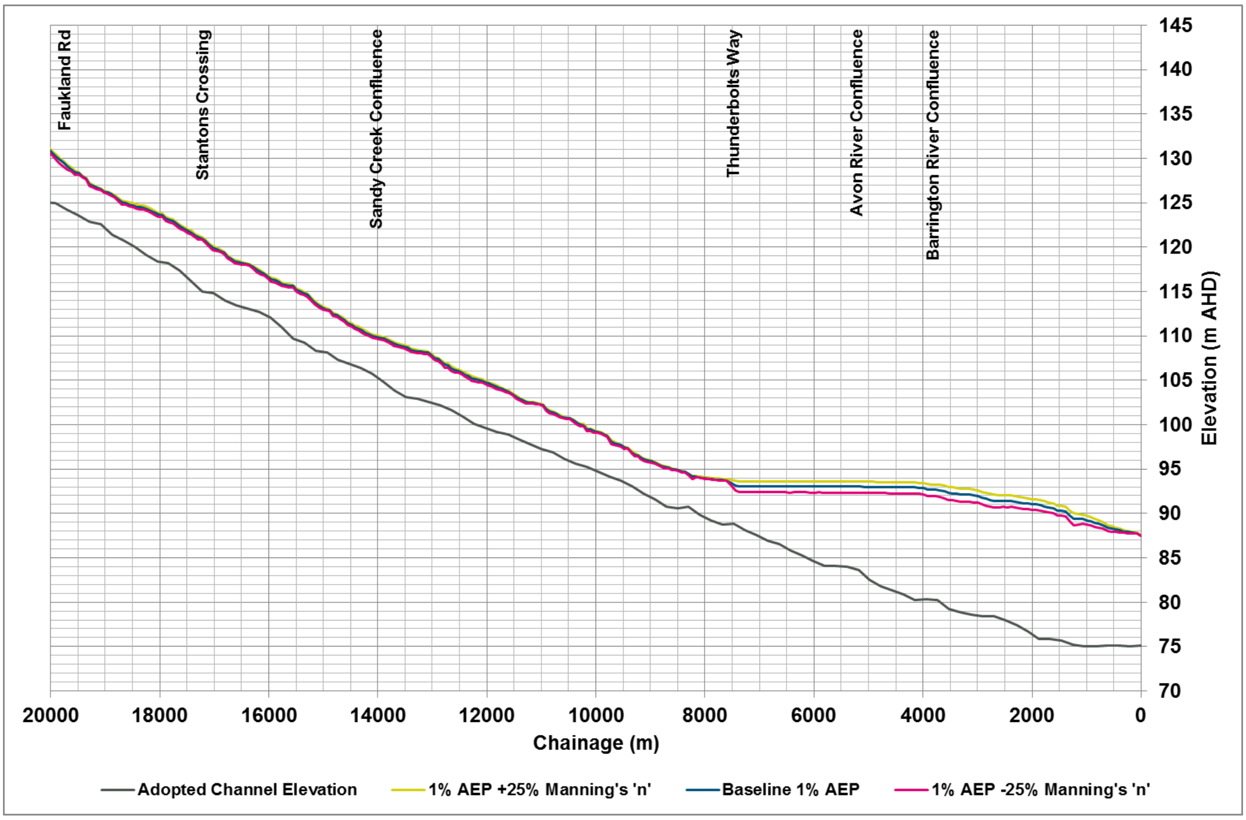


Figure 8-23 Gloucester River Sensitivity of Peak Flood Levels to Changes in Roughness

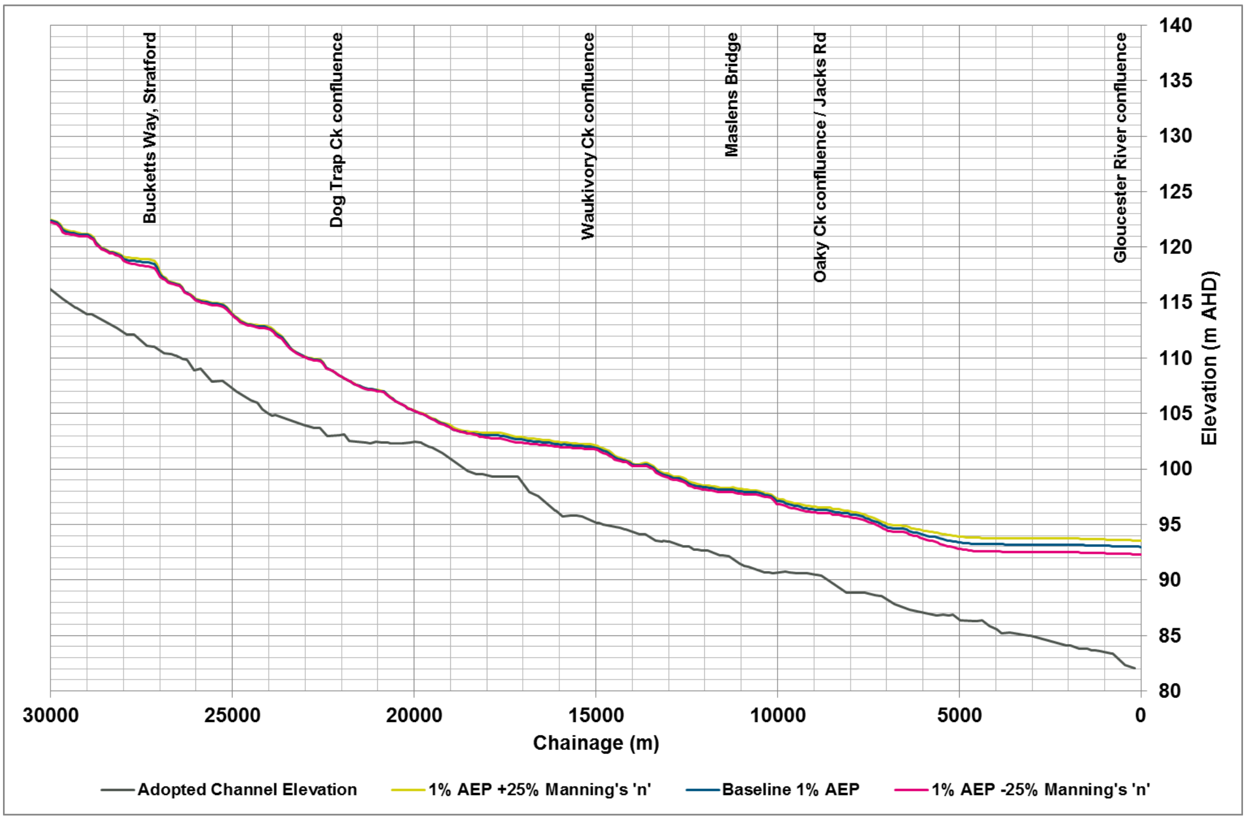


Figure 8-24 Avon River Sensitivity of Peak Flood Levels to Changes in Roughness

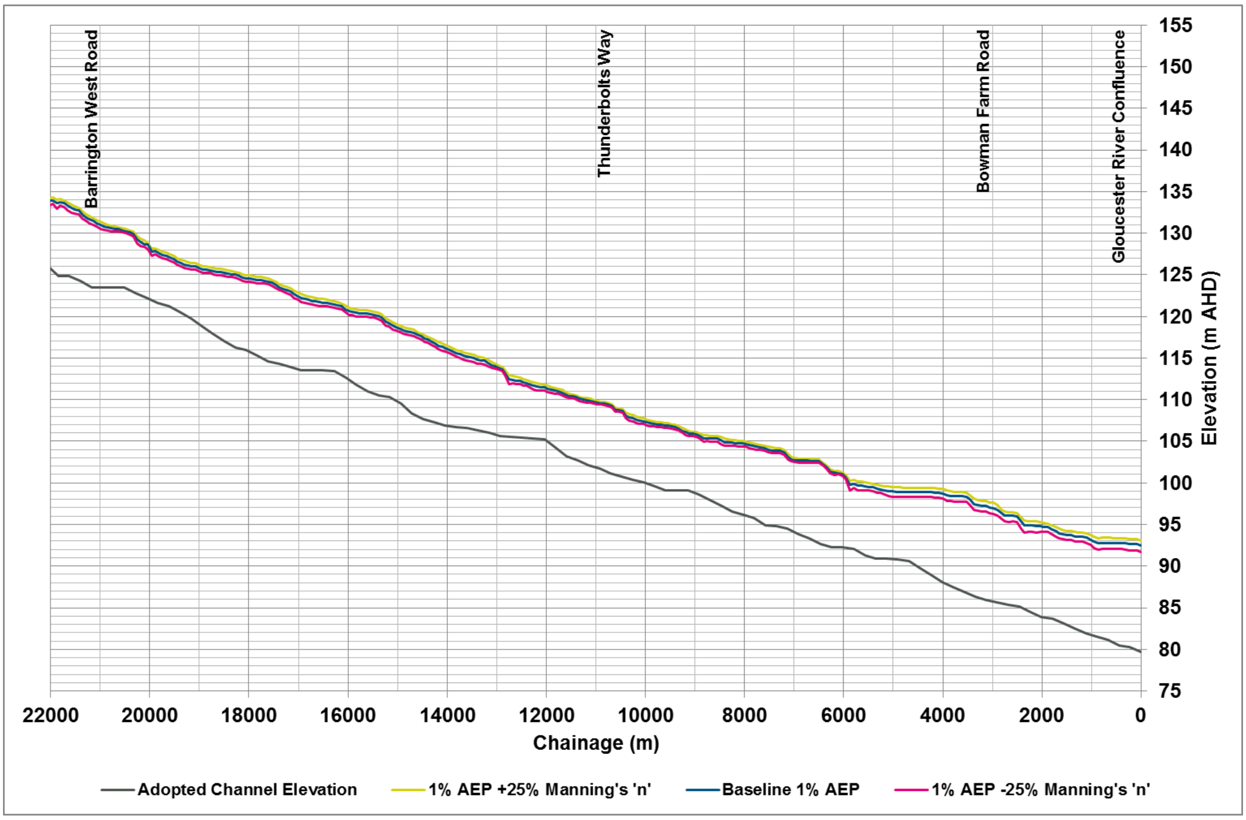


Figure 8-25 Barrington River Sensitivity of Peak Flood Levels to Changes in Roughness

The results of this sensitivity found that the modifications to the adopted channel bed elevation had little impact on the peak flood levels within the study area. Peak flood levels modelled along the Gloucester and Avon Rivers typically varied by around 0.03m as a result of raising and lowering the bed elevation. Given the extensive floodplain inundation at the 1% AEP flood level, minor changes in the in-channel conveyance have little impact on peak flood conditions. The wider, deeper nature of the Barrington River channel results in a greater proportion of floodwater conveyed in-channel compared to the Gloucester and Avon River systems. The sensitivity tests indicated that peak flood levels varied by up to 0.05m as a result of altering the bed elevation along the Barrington River.

8.6.4 Structure Blockage

In order to test the sensitivity of peak flood levels to potential structure blockages, all structures were modelled with a 25%, 50% and 100% blockage for the 20% AEP, 5% AEP and 1% AEP design events. The Avon River railway crossing spans 200m across the channel and floodplain just upstream of Gloucester. Blockages were applied to the bridge section over the channel only, as blockage of the entire floodplain in this location is highly unlikely.

Many structures within the catchment are large clear span bridges that are less likely to become blocked. Considering a range of different blockage scenarios for all bridges allows for the most likely blockage condition to be assessed. Modelled peak flood levels at reporting locations upstream of blocked structures are shown in Table 8-6, Table 8-7 and Table 8-8 for the 20% AEP, 5% AEP and 1% AEP design events for different blockage scenarios. The extent of impact for the worst case blockage scenario of 100% blockage is presented in Figure 8-26.

Table 8-6 Modelled Peak Flood Levels (m AHD) for 20% AEP Structure Blockage Scenarios

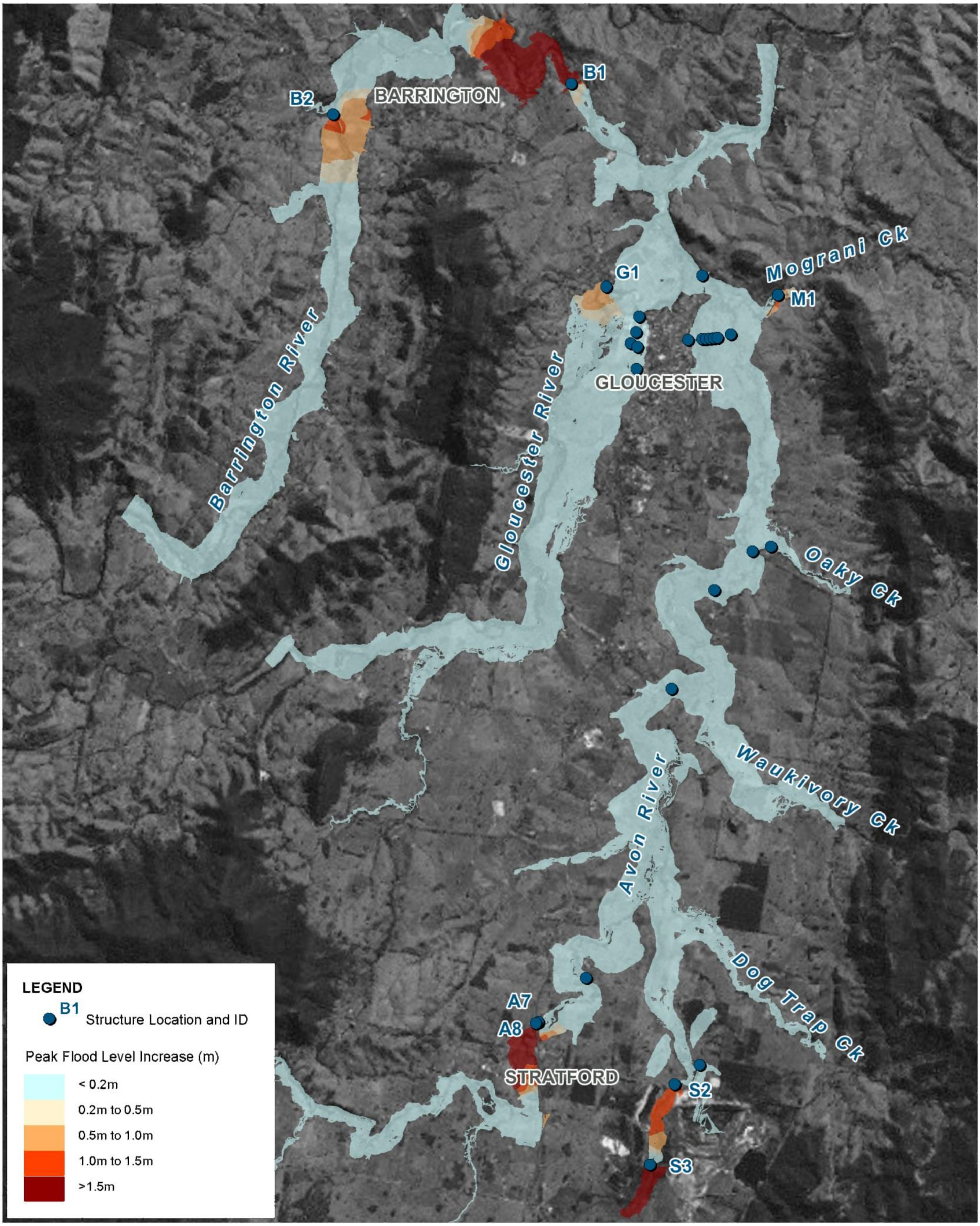
ID	Reporting Location	Scenario			
		Existing 20% AEP	25% Blockage 20% AEP	50% Blockage 20% AEP	100% Blockage 20% AEP
2	U/S Thunderbolts Way (Barrington)	106.6	106.8	107.6	109.4
3	U/S Bowman Farm Rd	91.4	91.5	92.4	98.8
6	U/S Stantons Ln	120.4	120.4	120.4	120.4
7	U/S Thunderbolts Way (Gloucester)	92.5	92.7	93.4	94.1
14	U/S Bucketts Way (Stratford)	116.5	116.6	116.8	120.2
15	U/S Wenhams Cox Rd	112.8	112.8	112.9	112.9
16	U/S Fairbairns Ln	100.9	100.9	100.9	100.9
18	U/S Maslens Ln	96.4	96.5	96.5	96.6
19	U/S Jacks Rd	94.8	94.8	94.9	94.9
20	U/S Bucketts Way (Gloucester)	89.6	89.6	89.9	90.6

Table 8-7 Modelled Peak Flood Levels (m AHD) for 5% AEP Structure Blockage Scenarios

ID	Reporting Location	Scenario			
		Existing 5% AEP	25% Blockage 5% AEP	50% Blockage 5% AEP	100% Blockage 5% AEP
2	U/S Thunderbolts Way (Barrington)	108.3	108.5	109.0	109.8
3	U/S Bowman Farm Rd	93.7	93.9	95.3	99.4
6	U/S Stantons Ln	121.1	121.1	121.1	121.1
7	U/S Thunderbolts Way (Gloucester)	93.0	93.2	93.7	94.3
13	U/S Crowthers Rd	118.0	118.1	118.1	120.5
14	U/S Bucketts Way (Stratford)	117.3	117.3	117.6	120.5
15	U/S Wenhams Cox Rd	113.7	113.7	113.7	113.7
16	U/S Fairbairns Ln	101.3	101.3	101.3	101.3
18	U/S Maslens Ln	96.7	96.8	96.8	96.8
19	U/S Jacks Rd	95.1	95.1	95.1	95.1
20	U/S Bucketts Way (Gloucester)	90.1	90.2	90.6	91.2

Table 8-8 Modelled Peak Flood Levels (m AHD) for 1% AEP Structure Blockage Scenarios

ID	Reporting Location	Scenario			
		Existing 1% AEP	25% Blockage 1% AEP	50% Blockage 1% AEP	100% Blockage 1% AEP
2	U/S Thunderbolts Way (Barrington)	109.3	109.4	109.8	110.6
3	U/S Bowman Farm Rd	96.8	97.3	99.0	100.5
6	U/S Stantons Ln	121.7	121.7	121.7	121.7
7	U/S Thunderbolts Way (Gloucester)	93.6	93.7	94.0	94.4
13	U/S Crowthers Rd	118.8	118.9	119.4	120.9
14	U/S Bucketts Way (Stratford)	118.5	118.7	119.3	120.8
15	U/S Wenhams Cox Rd	114.0	114.0	114.0	114.0
16	U/S Fairbairns Ln	102.2	102.2	102.2	102.2
18	U/S Maslens Ln	97.5	97.5	97.5	97.6
19	U/S Jacks Rd	96.1	96.1	96.1	96.1
20	U/S Bucketts Way (Gloucester)	93.2	93.2	93.2	93.2



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Impact of 100% Structure Blockage on the 1% AEP Event

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Table 8-9 Summary of Model Sensitivity Results

ID	Location	Modelled 1% AEP Peak Flood Level (m AHD)									
		Adopted Design	25% Increase Manning's	25% Decrease Manning's	Raise Bed	Lower Bed	+10% flow	+30% flow	25% Blockage	50% Blockage	100% Blockage
1	Barrington River at Forbesdale gauge	131.6	132.0	131.2	131.6	131.6	131.8	132.2	131.6	131.6	131.6
2	U/S Thunderbolts Way (Barrington)	109.3	109.5	109.1	109.3	109.3	109.4	109.7	109.4	109.8	110.6
3	U/S Bowman Farm Rd	96.8	97.4	96.2	96.9	96.7	97.3	98.4	97.3	99.0	100.5
4	Barrington River at Relfs Rd gauge	94.0	94.5	93.3	94.0	93.9	94.4	95.1	94.0	93.9	93.9
5	Gloucester River at Forbesdale gauge	128.5	128.7	128.3	128.5	128.5	128.6	128.8	128.5	128.5	128.5
6	U/S Stantons Ln	121.7	121.9	121.5	121.8	121.7	121.8	122.1	121.7	121.7	121.7
7	U/S Thunderbolts Way (Gloucester)	93.6	93.8	93.5	93.6	93.6	93.8	94.5	93.7	94.0	94.4
8	Gloucester River at Gloucester gauge	93.0	93.6	92.4	93.1	93.0	93.6	94.5	93.0	93.0	93.0
9	Confluence Gloucester/Avon Rivers	93.0	93.6	92.3	93.1	92.9	93.5	94.4	93.0	92.9	92.9
10	Confluence Gloucester/Barrington Rivers	92.4	93.1	91.6	92.5	92.4	93.0	93.9	92.4	92.4	92.4
11	D/S Gloucester River	91.4	92.0	90.7	91.5	91.3	92.0	92.9	91.4	91.3	91.4
12	U/S Deards Ln	131.1	131.2	131.0	131.0	131.1	131.1	131.2	131.1	131.1	131.1
13	U/S Crowthers Rd	118.8	119.0	118.5	119.0	118.7	118.9	119.2	118.9	119.4	120.9
14	U/S Bucketts Way (Stratford)	118.5	118.8	118.1	118.7	118.4	118.7	119.0	118.7	119.3	120.8
15	U/S Wenhams Cox Rd	114.0	114.1	113.9	114.0	114.0	114.0	114.1	114.0	114.0	114.0
16	U/S Fairbairns Ln	102.2	102.4	101.9	102.2	102.2	102.3	102.5	102.2	102.1	102.1
17	Avon River at DS Waukivory gauge	97.9	98.1	97.7	97.9	97.9	98.0	98.2	97.9	97.9	97.9
18	U/S Maslens Ln	97.5	97.7	97.3	97.5	97.5	97.6	97.8	97.5	97.5	97.6
19	U/S Jacks Rd	96.1	96.4	95.9	96.2	96.1	96.3	96.5	96.1	96.1	96.1
20	U/S Bucketts Way (Gloucester)	93.2	93.7	92.5	93.2	93.1	93.7	94.6	93.2	93.1	93.2

8.6.5 Impact of Proposed Developments

Council had requested that the potential flood impacts of a few proposed developments be assessed as part of the flood study. These include:

- The Stratford Mine Extension;
- The Rocky Hill Mine; and
- The Waukivory Pilot Testing Project.

It should be noted that these assessments are only high level and do not form detailed flood impact assessments. The purpose of these assessments was to provide Council with a verification of the more detailed impact assessments that had been undertaken for the proposed developments.

8.6.5.1 Stratford Mine Extension

The proposed extension of the Stratford Mine includes expansion to the north-east of existing operations, in the vicinity of Dog Trap Creek. There is limited information available relating to potential flood impacts. However, inspection of the available extent of the proposed extension indicates that any potential works are largely situated outside of the Dog Trap Creek floodplain and would not be expected to have significant flood impacts within the modelled watercourses.

8.6.5.2 Rocky Hill Mine

The proposed Rocky Hill Mine is situated to the east of the Avon River floodplain, between Waukivory Creek and Oaky Creek. A Flood Study for the proposed development has been undertaken by WRM and included a TUFLOW model of Waukivory Creek, Oaky Creek and the local reach of the Avon River. The study is comprehensive, including model calibration and a full range of design events.

As expected there are differences between the model results of the two studies. The main difference is the estimation of design flood flows. The Rocky Hill study has higher design flow estimates than those of this study, particularly for the more frequent flood events. This is due principally to the over estimation of design rainfall depths in the 1987 IFDs. The full representation of the Avon River floodplain upstream of the Rocky Hill site in this study may also provide for greater attenuation of the flood wave than does the hydrologic model representation in the Rocky Hill study.

The flood frequency analysis undertaken for the neighbouring Gloucester and Barrington River catchments has enabled a better estimation of local design flow conditions, especially for the more frequent flood events. The design peak flow estimates in the Rocky Hill study are around three times as large as the ones from this study for events up to the 5% AEP. The 2% AEP flows are around 70% higher and the 1% AEP flows are around 40% higher.

The design 1% AEP peak flood levels at selected locations were presented in the Rocky Hill study and enabled comparison with the flood levels from this study. The modelled flood peaks of the 1% AEP event are typically higher along the Avon River in the Rocky Hill study, most likely due to the higher flood flows.

The proposed barrier extents detailed in the study were incorporated into the TUFLOW model developed for this study and the 1% AEP design event was simulated in order to determine the flood impacts. The results of this produced impacts of an extent and magnitude similar to those which are presented in the Rocky Hill study.

8.6.5.3 Waukivory Pilot Testing Project

WRM used the TUFLOW model developed for the Rocky Hill Mine study to test the flood impacts for the pilot testing of four existing gas wells, which was detailed within a report. The most significant infrastructure associated with the pilot testing was the temporary deployment of noise barriers within the Avon River floodplain. These were incorporated into the Rocky Hill TUFLOW model to assess the impacts to the 1% AEP design flood.

A similar modelling exercise has been undertaken using the TUFLOW model developed for this study. The sound barrier locations were identified from the report details and were built into the model. The 1% AEP event was simulated with the sound barriers in place and the flood impacts were found to be of an extent and magnitude similar to those which are presented in the WRM study.

8.7 Comparison with Previous Studies

Given the relatively recent completion of the Gloucester Floodplain Management Study and Flood Study Supplementary Report in 2004, it is relevant to compare the results of the current study to those from the previous studies, in order to understand any potential differences.

8.7.1 Design Flood Flows

The design flood flows adopted in the current study differ somewhat to those used in 2004, as shown in Table 8-10. The flows in the current study are typically lower than the ones reported in the 2004 study, particularly for the more frequent flood events. The main reason behind this is the over estimation of design rainfall depths in the 1987 IFDs, as discussed in Section 7.2.1. This is more pronounced for the more frequent flood events and was acknowledged within the 2004 study. The design flows for the 20% AEP event are only around 50% of those adopted in 2004. However, for the 1% AEP event the flow rates from the two studies are typically within around 10% of each other.

8.7.2 Design Flood Levels

The key outcome from the studies is the 1% AEP flood levels, which are used to determine the flood planning area and minimum floor levels for residential developments. The differences between the modelled design peak flood levels in the current and previous studies will vary spatially. However, as an indicative representation of flood conditions in Gloucester the peak flood levels at the Church Street and Denison Street intersection have been presented in Table 8-11. The recorded levels of some of the key historic flood events have also been included for comparison.

Table 8-10 Comparison of Design Flood Flows from the 2004 and 2014 Studies

Catchment (Study)	Modelled Peak Flows for the Design Flood Events (m^3/s)					
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Gloucester (2014)	240	360	480	740	960	3150
Gloucester (2004)	*490*	*630*	*800*	*1040*	*1240*	*4640*
Avon (2014)	190	280	330	660	870	2770
Avon (2004)	*460*	*560*	*690*	*860*	*1020*	*3390*
Barrington (2014)	600	890	1200	1890	2550	9430
Barrington (2004)	*1050*	*1320*	*1710*	*2240*	*2660*	*7250*
Combined (2014)	900	1460	1900	3150	4220	15300
Combined (2004)	*1940*	*2410*	*3050*	*3920*	*4640*	*14300*

The intersection does not become flooded until a level of almost 92.5m and so the levels presented for the 20% AEP and 10% AEP events in the 2004 studies are most likely indicative of the lower limit of the model cross section at this location. For the current study, when levels are below 92.5m AHD the level has been taken from The Billabong upstream of Denison Street.

It can be seen from Table 8-11 that in the current study the 2011, 1978 and 1956 flood events represent around a 10% AEP, 5% AEP and 2% AEP in Gloucester (at the Church Street and Denison Street intersection) respectively. The 1929 flood event represents around a 1% AEP design condition. The previous study placed the 1956 flood event at around the 5% AEP design condition, with the 1929 flood event at around the 1% AEP design condition. Consistent with the comparison of design flood flows in Section 8.7.1, the current study provides lower peak flood levels for the more frequent flood events, but is similar at the 1% AEP flood magnitude. This suggests that the flood planning area derived from the current study should be reasonably similar to that derived in 2004.

Table 8-11 Comparison of Peak Flood Levels at Gloucester from the 2004 and 2014 Studies

Flood Event	Peak Flood Level (m AHD)	
	2014 Study	2004 Study
20% AEP	91.3	92.45
2011	*91.8*	*91.8*
10% AEP	91.9	92.40
5% AEP	92.4	92.95
1978	*92.5*	*92.5*
1956	*92.9*	*92.9*
2% AEP	93.1	93.25
1% AEP	93.5	93.45
1929	*93.5*	*93.5*
PMF	102.4	99.10

9 Floodplain Risk Management Considerations

9.1 Flood Damages Assessment

9.1.1 Types of Flood Damage

The definitions and methodology used in estimating flood damage are summarised in the Floodplain Development Manual. Figure 9-1 summarises the “types” of flood damages as considered in this study. The two main categories are 'tangible' and 'intangible' damages. Tangible flood damages are those that can be more readily evaluated in monetary terms, while intangible damages relate to the social cost of flooding and therefore are much more difficult to quantify.

Tangible flood damages are further divided into direct and indirect damages. Direct flood damages relate to the loss, or loss in value, of an object or a piece of property caused by direct contact with floodwaters. Indirect flood damages relate to loss in production or revenue, loss of wages, additional accommodation and living expenses, and any extra outlays that occur because of the flood.

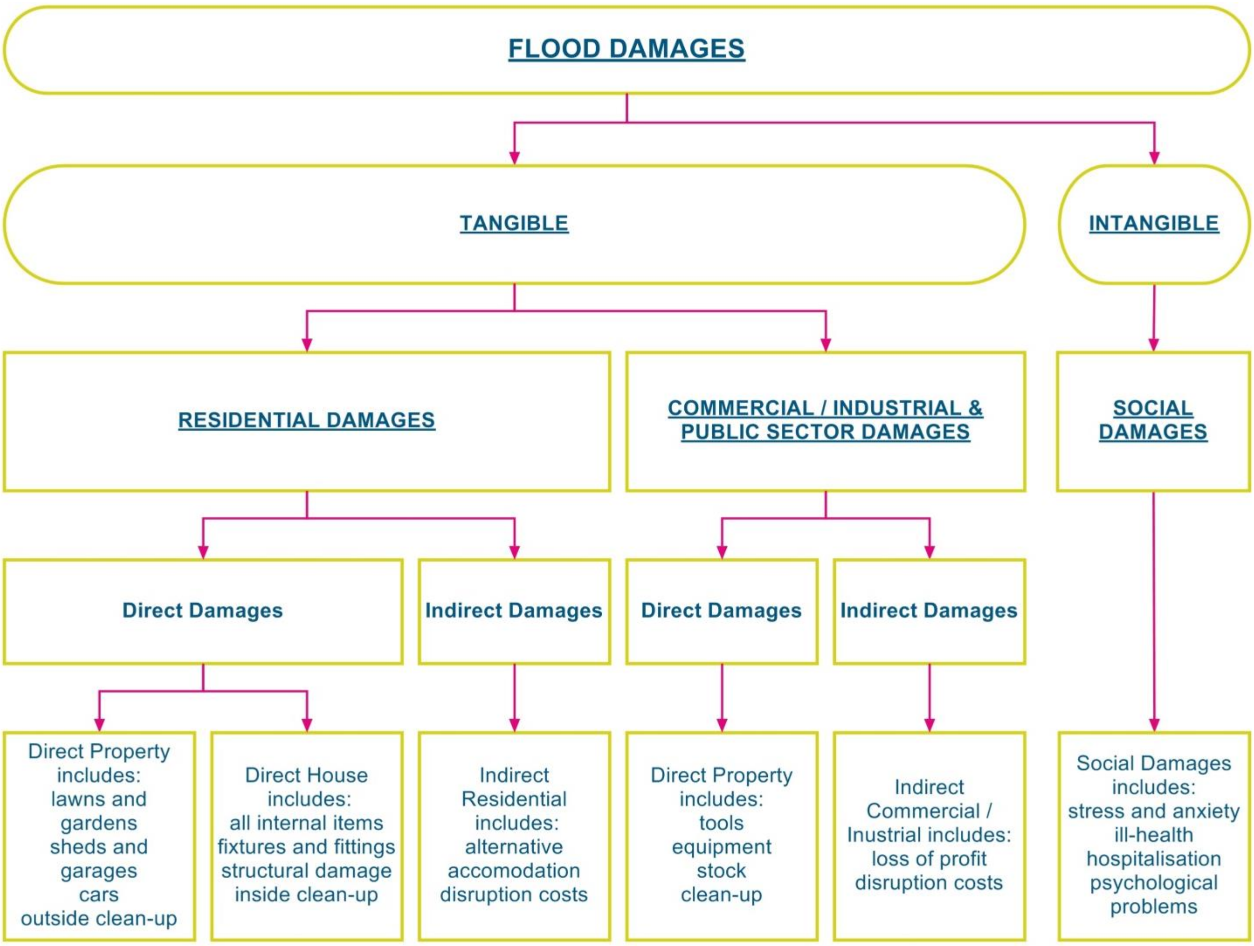


Figure 9-1 Types of Flood Damage

9.1.2 Basis of Flood Damage Calculations

Flood damages have been calculated using the data base of potentially flood affected properties and a number of stage-damage curves derived for different types of property within the catchment. These curves relate the amount of flood damage that would potentially occur at different depths of inundation, for a particular property type. Residential damage curves are based on the OEH guideline stage-damage curves for residential property.

The property floor level survey acquired for the Gloucester Floodplain Management Study has been used for the database of flood affected properties. Properties located within the floodplain that did not have floor level survey available were estimated from the LiDAR DEM, assuming a floor level 0.4m above ground.

Different stage-damage curves for direct property damage have been derived for:

- Residential dwellings (categorised into small, typical or raised categories); and
- Commercial premises (categorised into low, medium or high damage categories).

Apart from the direct damages calculated from the derived stage-damage curves for each flood affected property, other forms of flood damage include:

- Indirect residential, commercial and industrial damages, taken as a percentage of the direct damages;
- Infrastructure damage, based on a percentage of the total value of residential and business flood damage; and
- Intangible damages relate to the social impact of flooding and include:
    - inconvenience,
    - isolation,
    - disruption of family and social activities,
    - anxiety, pain and suffering, trauma,
    - physical ill-health, and
    - psychological ill-health.

The damage estimates derived in this study are for the **tangible damages only**. Whilst intangible losses may be significant, these effects have not been quantified due to difficulties in assigning a meaningful dollar value.

9.1.3 Assessment of Direct Damages

The peak depth of flooding was determined at each property for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events and the PMF. The associated direct flood damage cost to each property was subsequently estimated from the stage-damage relationships. For residential properties the flood damage curves include external damages incurred below floor level, the majority of which would be associated with damage to vehicles. For external damages where the flood depth is below 0.3m a nominal $1,000 value has been adopted. Total damages for each flood event were determined by summing the predicted damages for each individual property.

The Average Annual Damage (AAD) is the average damage in dollars per year that would occur in a designated area from flooding over a very long period of time. In many years there may be no flood damage, in some years there will be minor damage (caused by small, relatively frequent floods) and, in a few years, there will be major flood damage (caused by large, rare flood events). Estimation of the AAD provides a basis for comparing the effectiveness of different floodplain management measures (i.e. the reduction in the AAD).

9.1.4 Estimation of Indirect Damages

The indirect damages are more difficult to determine and would vary for each flood event, particularly with the duration of the flood inundation. Previous studies detailing flood damages from actual events have found that the indirect damages for residential properties are typically in the order of 20% of the direct damages. The Gloucester Floodplain Management Study determined the indirect damages more specifically, but was between 13% and 22% of the direct damages across the range of flood events. Given the relative uncertainty associated with the indirect damages a value of 20% of the direct damages has been adopted for this study.

The indirect damages associated with commercial properties are typically higher and a value of 40% of the calculated direct damages has been adopted.

9.1.5 Residential Flood Damages

The assessment of the residential flood damages is presented in Table 9-1. From this data the AAD for residential properties was calculated as being $126,000 in direct damages and $25,000 in indirect damages, giving a total value of $151,000.

Table 9-1 Summary of Residential Flood Damages

Design Event	Denison Street Flood Level (m AHD)	Properties Flooded Above Floor (and Ground)	Direct Damages ($)	Indirect Damages ($)	Total Damages ($)
50% AEP	90.5	0 (0)	$-	$-	$-
20% AEP	91.3	0 (1)	$1,000	$200	$1,200
10% AEP	91.9	0 (2)	$2,000	$400	$2,400
5% AEP	92.4	1 (8)	$77,000	$15,000	$92,000
2% AEP	93.1	13 (25)	$842,000	$168,000	$1,010,000
1% AEP	93.5	31 (42)	$2,389,000	$478,000	$2,867,000
0.5% AEP	94.6	56 (64)	$4,733,000	$947,000	$5,680,000
0.2% AEP	96.5	108 (126)	$10,275,000	$2,055,000	$12,330,000
PMF	102.4	401 (428)	$43,096,000	$8,619,000	$51,715,000

9.1.6 Caravan Park Flood Damages

The flood damages associated with the caravan park are more difficult to assess, given the mobile nature of on-site residence. For the purposes of this assessment a total number of residences of 42 has been assumed. The assessment of the caravan park flood damages is presented in Table 9-2. From this data the AAD for caravan park properties was calculated as being $48,000 in direct damages and $10,000 in indirect damages, giving a total value of $58,000.

Table 9-2 Summary of Caravan Park Flood Damages

Design Event	Denison Street Flood Level (m AHD)	Properties Flooded Above Floor (and Ground)	Direct Damages ($)	Indirect Damages ($)	Total Damages ($)
50% AEP	90.5	0 (0)	$-	$-	$-
20% AEP	91.3	0 (0)	$-	$-	$-
10% AEP	91.9	0 (0)	$-	$-	$-
5% AEP	92.4	0 (0)	$-	$-	$-
2% AEP	93.1	12 (30)	$737,000	$147,000	$884,000
1% AEP	93.5	30 (42)	$1,262,000	$252,000	$1,514,000
0.5% AEP	94.6	36 (42)	$2,024,000	$405,000	$2,429,000
0.2% AEP	96.5	42 (42)	$4,301,000	$860,000	$5,161,000
PMF	102.4	42 (42)	$4,937,000	$987,000	$5,924,000

9.1.7 Commercial Flood Damages

The assessment of the commercial flood damages is presented in Table 9-3. From this data the AAD for commercial properties was calculated as being $265,000 in direct damages and $106,000 in indirect damages, giving a total value of $371,000.

Table 9-3 Summary of Commercial Flood Damages

Design Event	Denison Street Flood Level (m AHD)	Properties Flooded Above Floor	Direct Damages ($)	Indirect Damages ($)	Total Damages ($)
50% AEP	90.5	0	$-	$-	$-
20% AEP	91.3	0	$-	$-	$-
10% AEP	91.9	5	$149,000	$60,000	$209,000
5% AEP	92.4	12	$631,000	$252,000	$883,000
2% AEP	93.1	60	$3,488,000	$1,395,000	$4,883,000
1% AEP	93.5	74	$6,771,000	$2,708,000	$9,479,000
0.5% AEP	94.6	81	$12,342,000	$4,937,000	$17,279,000
0.2% AEP	96.5	94	$16,126,000	$6,450,000	$22,576,000
PMF	102.4	99	$18,705,000	$7,482,000	$26,187,000

9.1.8 Public Utilities Damages

Public utilities include roads, railways, parklands and underground water, sewerage, power and telephone services and installations. The damages sustained by public utilities comprise the replacement or repair of assets damaged by floodwaters, the cost of clean-up of the installations as well as the collection and disposal of clean-up material from private property.

Within the Gloucester Floodplain Management Plan the estimates of flood damages to public utilities were calculated assuming a cost of $7,900 per hectare. For the purposes of this study a similar approach has been adopted, albeit the cost per hectare has been increased to $12,000 to account for inflation since 2004.

The extent of the Gloucester urban area was defined from the aerial photography and the flooded area of this determined for each design event. Given that the flood waters remain largely in-bank for the 20% AEP event, the flooded urban area under this condition was assumed to have a negligible clean-up cost. As 16ha of urban area were flooded in the 20% AEP event 16ha was subtracted from the flooded urban area of the larger events. The assessment of public utilities damages is presented in Table 9-4. From this data the AAD for public utilities was calculated as being $47,000.

Table 9-4 Summary of Public Utilities Flood Damages

Design Event	Denison Street Flood Level(m AHD)	Area of Urban Area Flooded (ha)	Total Damages ($)
50% AEP	90.5	-	$-
20% AEP	91.3	-	$-
10% AEP	91.9	14	$168,000
5% AEP	92.4	27	$324,000
2% AEP	93.1	44	$528,000
1% AEP	93.5	52	$624,000
0.5% AEP	94.6	58	$696,000
0.2% AEP	96.5	67	$804,000
PMF	102.4	115	$1,380,000

9.1.9 Total Tangible Flood Damages

The total tangible flood damages for residential, caravan park and commercial properties and the damage to public utilities were combined, as presented in Table 9-5. From this data the combined AAD was calculated as being $627,000, comprised as follows:

- $151,000 from residential properties;
- $58,000 from properties within the caravan park;
- $371,000 from commercial properties; and
- $47,000 from public utilities.

Table 9-5 Summary of Total Tangible Flood Damages

Design Event	Residential Flood Damages ($)	Caravan Park Flood Damages ($)	Commercial Flood Damages ($)	Public Utilities Flood Damages ($)	Total Tangible Flood Damages ($)
50% AEP	$-	$-	$-	$-	$-
20% AEP	$1,200	$-	$-	$-	$1,200
10% AEP	$2,400	$-	$209,000	$168,000	$379,400
5% AEP	$92,000	$-	$883,000	$324,000	$1,299,000
2% AEP	$1,010,000	$884,000	$4,883,000	$528,000	$7,305,000
1% AEP	$2,867,000	$1,514,000	$9,479,000	$624,000	$14,484,000
0.5% AEP	$5,680,000	$2,429,000	$17,279,000	$696,000	$26,084,000
0.2% AEP	$12,330,000	$5,161,000	$22,576,000	$804,000	$40,871,000
PMF	$51,715,000	$5,924,000	$26,187,000	$1,380,000	$85,206,000
AAD	**$151,000**	**$58,000**	**$371,000**	**$47,000**	**$627,000**

9.2 Flood Planning Level

Flood Planning Levels (FPLs) are used for planning purposes, and directly determine the extent of the Flood Planning Area (FPA), which is the area of land subject to flood-related development controls. The FPL is the level below which a Council places restrictions on development due to the hazard of flooding. Traditional floodplain planning has relied almost entirely on the definition of a singular FPL, which has usually been based on the 1% AEP flood level, for the purposes of applying floor level controls.

Adoption of a single FPL can provide for:

- Unnecessary restriction of some land uses from occurring below the FPL, while allowing other inappropriate land uses to occur immediately above the FPL; and
- Lack of recognition of the significant flood hazard that may exist above the FPL (and as a result, there are very few measures in place to manage the consequences of flooding above the FPL).

The latter point above is particularly relevant to flooding in Gloucester. As discussed, the nature of flooding is such that there are significant increases in flood depth with increasing flood magnitude. For example, the 0.5% AEP flood level along Church Street is between 0.5m and 1.2m above the 1% AEP flood level. Accordingly, even with a 0.5m freeboard provision above the 1% AEP level, above floor flooding would be expected for a 0.5% AEP event.

It is important also to recognise the inherent uncertainties in design flood prediction. For example, climate change sensitivity tests on design rainfall depths (see Section 8.6.1) show the potential for large variations in peak flood levels over and above the adopted design levels. A 10% and 30% increase in the adopted 1% AEP design rainfall depth (within a typical range of sensitivity) provides for increases in predicted 1% AEP flood levels at the Church Street and Denison Street intersection of 0.3 and 1.1m respectively.

Similarly, the PMF level in Gloucester lies some 9m above the 1% AEP level. Typically this scale of event is used to assess risk to life, however, it must be considered in conjunction with other development controls applied at lower flood thresholds. Approving development within the floodplain (defined up to the PMF level) inherently provides for flood risk. Some considerations of the impact of events of greater magnitude than the flood planning levels include:

- Evacuation opportunity – appreciating that with the combination of relatively short warning times and potential access road inundation, residents could become confined to their property and immediate surrounds, with only pedestrian access. Given the local topography of Gloucester, in most instances a constantly rising evacuation route (i.e. walk up the hill) will be available in the case of major flooding. Should residents fail to evacuate prior to property becoming inundated, there is the possibility that flood levels could exceed roof levels. Personal flood action plans should recognise this risk;
- Property damage – with potential for significant inundation above the FPL, structural integrity of property constructed on the floodplain is essential. Whilst evacuation is the primary objective, structural integrity of the property is required for people sheltering in place.

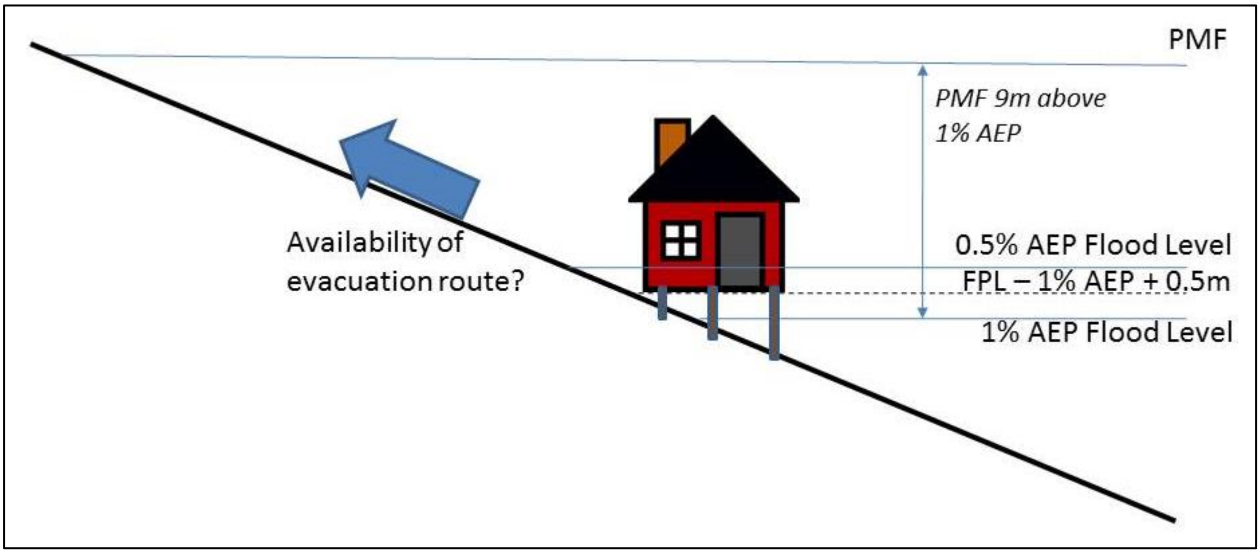


Figure 9-2 The FPL and relation to a range of flood event magnitudes

The current design planning level for Gloucester defined in Council's DCP is 0.5m above the Designated Flood level. The Gloucester Floodplain Management Study had recommend the adoption of the 1% AEP levels as the Designated Flood for development within existing residential zoned land and the PMF levels as the Designated Flood for development within future residential rezoning.

The above flood planning level definitions in conjunction with the adopted design flood levels from this study are considered to be suitable on the following basis:

- The level reflects an acceptable level of risk to property (in terms of potential flood damage) considering likelihood of flooding and relative consequences. The adopted flood levels represent the best estimates of design flood levels given available information and established by industry best practice;

- Risk to life more effectively managed by other controls/measures such as specific requirements for evacuation route provisions in the DCP, effective flood warning and emergency response. Risk to life is not managed effectively in Gloucester through a raised flood planning level due to the nature of flooding (i.e. residual risks up to the PMF event);
- Consistency across the Gloucester Shire LGA is maintained; and
- The setting of the flood planning level does not preclude property to be constructed at a higher level. Flood risk information across the range of flood events, including events greater than the 1% AEP event, should be made available to landholders and development proponents. DCP provisions may be included to encourage development at higher levels where opportunities exist on appropriate lots, noting available flood level information.

The recommended flood planning area (i.e. area under the recommended FPLs) is presented in the flood mapping compendium.

9.3 Flood Emergency Response

9.3.1 Flood Warning

9.3.1.1 Existing Flood Warning System

The BoM Flood Warning Service provides different types of information to inform the community of type of flooding and the level of flood risk. The range of information may include (BoM, 2013):

- **An Alert, Watch or Advice** of possible flooding, if flood producing rain is expected to happen in the near future. The general weather forecasts can also refer to flood producing rain.
- **A Generalised Flood Warning** that flooding is occurring or is expected to occur in a particular region. No information on the severity of flooding or the particular location of the flooding is provided. These types of warnings are issued for areas where no specialised warnings systems have been installed. As part of its Severe Weather Warning Service, the Bureau also provides warnings for severe storm situations that may cause flash flooding. In some areas, the Bureau is working with local councils to install systems to provide improved warnings for flash flood situations.
- **Warnings of 'Minor', 'Moderate' or 'Major' flooding** in areas where the Bureau has installed specialised warning systems. In these areas, the flood warning message will identify the river valley, the locations expected to be flooded, the likely severity of the flooding and when it is likely to occur.
- **Predictions of the expected height of a river** at a town or other important locations along a river, and the time that this height is expected to be reached. This type of warning is normally the most useful in that it allows local emergency authorities and people in the flood threatened area to more precisely determine the area and likely depth of the flooding. This type of warning can only be provided where there are specialised flood warning systems and where flood forecasting models have been developed.

There is currently no formal flood warning service for the Gloucester River provided by the Bureau of Meteorology (BoM).

Flood classifications in the form of locally-defined flood levels are used in flood warnings to give an indication of the severity of flooding (minor, moderate or major) expected.

The SES classifies major, moderate and minor flooding according to the gauge height values at the Gloucester (Lehmans Flat Bridge) gauge, as detailed in Table 9-6. The flood classification levels are described by:

- **Minor flooding:** flooding which causes inconvenience such as closing of minor roads and the submergence of low-level bridges. The lower limit of this class of flooding, on the reference gauge, is the initial flood level at which landholders and/or townspeople begin to be affected in a significant manner that necessitates the issuing of a public flood warning by the BoM.
- **Moderate flooding:** flooding which inundates low-lying areas, requiring removal of stock and/or evacuation of some houses. Main traffic routes may be flooded.
- **Major flooding:** flooding which causes inundation of extensive rural areas, with properties, villages and towns isolated and/or appreciable urban areas flooded.

Table 9-6 Flood Warning Levels and Design Flood Levels at Gloucester

Flood Classification	Forbesdale Gauge Height (m)	Forbesdale Flood Level (m AHD)	Gloucester Gauge Height (m)	Gloucester Gauge Flood Level (m AHD)
50% AEP	2.1	126.7	4.2	89.1
Minor Flood Warning	**-**	**-**	**4.3**	**89.2**
Moderate Flood Warning	**-**	**-**	**4.9**	**89.8**
20% AEP	2.8	127.4	5.0	89.8
Major Flood Warning	**-**	**-**	**5.2**	**90.1**
10% AEP	3.1	127.7	5.3	90.2
5% AEP	3.3	127.9	5.6	90.5
2% AEP	3.6	128.3	6.8	91.7
1% AEP	3.9	128.5	8.2	93.0
0.5% AEP	4.2	128.8	9.6	94.5
0.2% AEP	4.6	129.2	11.6	96.4
PMF	6.0	130.6	17.5	102.4

There are also a number of general warning services provided by the Bureau including:

- **Flood Watches –** typically provide 24-48 hour notice. These are issued by the NSW Flood Warning Centre providing initial warnings of potential flooding based upon current catchment conditions and future rainfall predictions.

- **Severe Thunderstorm Warnings –** typically provide 0.5 to 2 hours' notice. These short range forecasts are issued by the Bureau's severe weather team and are based upon radar, data from field stations, reports from storm spotters as well as synoptic forecasts.
- **Severe Weather Warnings –** for synoptic scale events that cause a range of hazards, including flooding. Examples of synoptic scale events are the deep low pressure systems off the NSW coast such as that which produced the 2007 flood in Newcastle and the wider Hunter region.

No alterations to the existing flood warning system are recommended. However, given that the flood levels at the Gloucester gauge can be influenced by flooding on the Avon and Barrington Rivers it is worth also considering the water levels at the Forbesdale gauge, as it is flood flows on the Gloucester River that are the principal driver of flood conditions along The Billabong.

The Sandy Creek tributary joins the Gloucester River downstream of Forbesdale and so the translation of flood levels at the gauge to resultant flooding in Gloucester should be treated with some caution. Should significantly higher rainfall between Forbesdale and Gloucester occur than over the upper Gloucester River catchment, then the Forbesdale flood levels may underestimate conditions in Gloucester (or vice versa). The design gauge heights and flood levels for the Gloucester River at Forbesdale have therefore been presented alongside those for the Gloucester gauge in Table 9-6.

9.3.1.2 Available Flood Warning

The amount of warning available for an approaching flood can have a significant impact on the risk to life. Less warning time clearly represents a greater risk to the community, as there is less opportunity to implement risk-reduction measures. Minimal warning time also means that emergency services are unlikely to be able to provide any assistance or direction for affected communities.

The rate of rise of floodwaters is typically a function of the catchments topographical characteristics such as size, shape and slope, and also influences such as soil types and land use. Flood levels rise faster in steep, constrained areas and slower in broad, flat floodplains. A high rate of rise adds an additional hazard by reducing the amount of time available to prepare and evacuate.

Given the relative steepness of the Gloucester River catchment, the flood response of the catchment will be relatively fast. However, the water level gauges at Forbesdale and Gloucester provide an indication of potential flooding in Gloucester. Figure 9-3 shows the modelled flood level on The Billabong at Denison Street for the 1% AEP event, alongside the design rainfall hyetograph. It can be seen that the flood waters rise relatively quickly at between 0.5m and 1m per hour. For this design condition the flood levels in The Billabong begin to rise rapidly at around 16 hours from the onset of rainfall. However, this flood response occurs after around eight hours at the Gloucester gauge, giving a reasonable amount of time to monitor and respond to rising flood conditions.

9.3.2 Emergency Response

The State Emergency Service (SES) has formal responsibility for emergency management operations in response to flooding. Other organisations normally provide assistance, including the

Bureau of Meteorology, Council, police, fire brigade, ambulance and community groups. Emergency management operations are usually outlined in a Local Flood Plan.

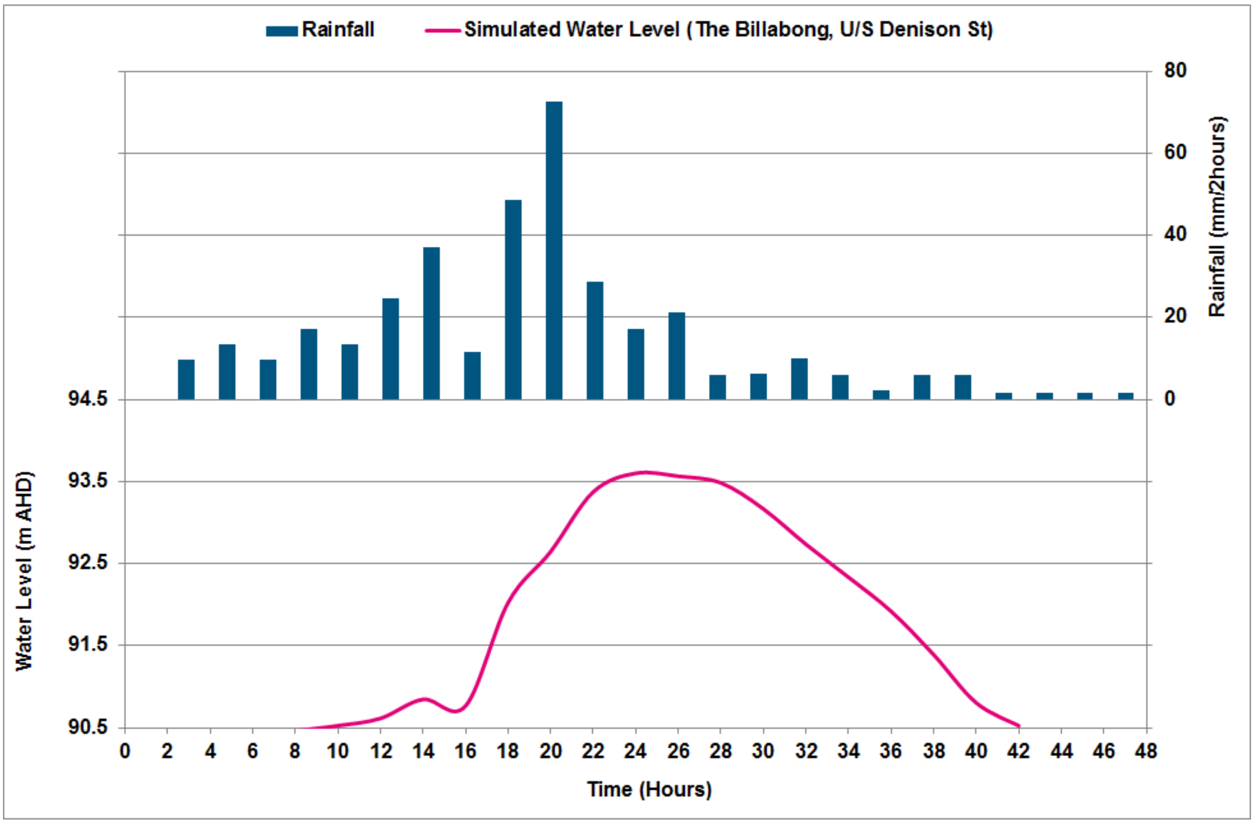


Figure 9-3 Rate of Rise of Floodwater for the 1% AEP Event

SES actions during the event of a flood in Gloucester are guided by the Flood Intelligence Card for the Gloucester gauge. This contains information on key flood heights at the gauge, flooding consequences and required actions. Details contained within this study report and design flood mapping will provide useful information with which to update the Flood Intelligence Card.

Most of the flood affected areas in Gloucester are readily evacuated to adjacent higher ground. The main exception to this is the caravan park, where access roads are cut before inundation of the site occurs. Access to the park via Boundary Street to the south is cut from around the 5% AEP event, albeit to depths of less than 0.2m. At the 10% AEP event the southern Boundary Street access becomes un-trafficable. Access via Boundary Street to the north would also be inundated, but to a maximum depth of less than 0.3m. At the 5% AEP event the inundation of Boundary Street becomes more extensive, with peak flood depths of up to 0.4m across the northern access and potentially high velocities. At the 2% AEP event the caravan park itself becomes inundated and Boundary Street is flooded to depths in excess of 1m.

In addition to the caravan park access there are a number of major access road that are subject to flood inundation. These include the Thunderbolts Way between The Billabong and Church Street and also across the Barrington Flats; and the Bucketts Way across the Avon floodplain. Modelled design flood conditions at these locations have been summarised in Table 9-7.

Table 9-7 Summary of Major Access Road Inundation

Flood Event	Thunderbolts Way at Gloucester		Thunderbolts Way at Barrington		Bucketts Way at Gloucester	
	Peak Flood Depth (m)	Peak Flood Velocity (m/s)	Peak Flood Depth (m)	Peak Flood Velocity (m/s)	Peak Flood Depth (m)	Peak Flood Velocity (m/s)
50% AEP	-	-	-	-	-	-
20% AEP	-	-	-	-	-	-
10% AEP	0.1	0.7	0.2	0.7	-	-
5% AEP	0.5	0.8	0.4	1.3	-	-
2% AEP	1.4	0.8	0.7	2.5	1.2	2.0
1% AEP	2.0	0.8	1.2	2.5	2.6	2.5
0.5% AEP	3.3	0.8	1.7	3.0	4.0	1.6
0.2% AEP	5.2	0.8	2.4	2.5	5.9	0.5
PMF	11	0.2	5.0	3.0	12	0.3

9.3.3 Classification of Communities

The SES classifies communities according to the impact that flooding has on them. The primary purpose for doing this is to assist SES in the planning and implementation of response strategies. Flood impacts relate to where the normal functioning of services is altered due to a flood, either directly or indirectly, and relates specifically to the operational issues of evacuation, resupply and rescue.

Flood Islands

Flood Islands are inhabited areas of high ground within a floodplain which are linked to the flood free valley sides by only one access / egress route. If the road is cut by floodwaters, the community becomes an island, and access to the area may only be gained by boat or aircraft. Flood islands are classified according to what can happen after the evacuation route is cut as and are typically separated into:

- High Flood Islands;
- Low Flood Islands

A *High Flood Island* include sufficient land located at a level higher than the limit of flooding (i.e., above the PMF) to provide refuge to occupants. During flood events properties may be inundated and the community isolated, however, as there is an opportunity for occupants to retreat to high ground, the direct risk to life is limited. If it will not be possible to provide adequate support during the period of isolation, evacuation will have to take place before isolation occurs.

The highest point of a *Low Flood Island* is lower than the limit of flooding (i.e., below the PMF) or does not provide sufficient land above the limit of flooding to provide refuge to the occupants of the area. During flood events properties may be inundated and the community isolated. If floodwater continues to rise after it is isolated, the island will eventually be completely covered. People left stranded on the island may drown.

Trapped Perimeter Areas

Trapped Perimeter Areas are inhabited areas located at the fringe of the floodplain where the only practical road or overland access is through flood prone land and unavailable during a flood event. The ability to retreat to higher ground does not exist due to topography or impassable structures. Trapped perimeter areas are classified according to what can happen after the evacuation route is cut as follows.

High Trapped Perimeter Areas include sufficient land located at a level higher than the limit of flooding (i.e., above the PMF) to provide refuge to occupants. During flood events properties may be inundated and the community isolated, however, as there is an opportunity for occupants to retreat to high ground, the direct risk to life is limited. If it will not be possible to provide adequate support during the period of isolation, evacuation will have to take place before isolation occurs.

Low Trapped Perimeter Areas is lower than the limit of flooding (i.e., below the PMF) or does not provide sufficient land above the limit of flooding to provide refuge to the occupants people of the area. During a flood event the area is isolated by floodwater and property may be inundated. If floodwater continues to rise after it is isolated, the area will eventually be completely covered. People trapped in the area may drown.

Areas Able to be Evacuated

These are inhabited areas on flood prone fringe areas that are able to be evacuated. However, their categorisation depends upon the type of evacuation access available, as follows.

Areas with Overland Escape Route are those areas where access roads to flood free land cross lower lying flood prone land. Evacuation can take place by road only until access roads are closed by floodwater. Escape from rising floodwater is possible but by walking overland to higher ground. Anyone not able to walk out must be reached by using boats and aircraft. If people cannot get out before inundation, rescue will most likely be from rooftops.

Areas with Rising Road Access are those areas where access roads rising steadily uphill and away from the rising floodwaters. The community cannot be completely isolated before inundation reaches its maximum extent, even in the PMF. Evacuation can take place by vehicle or on foot along the road as floodwater advances. People should not be trapped unless they delay their evacuation from their homes. For example people living in two storey homes may initially decide to stay but reconsider after water surrounds them.

These communities contain low-lying areas from which people will be progressively evacuated to higher ground as the level of inundation increases. This inundation could be caused either by direct flooding from the river system or by localised flooding from creeks.

Indirectly Affected Areas

These are areas which are outside the limit of flooding and therefore will not be inundated nor will they lose road access. However, they may be indirectly affected as a result of flood damaged infrastructure or due to the loss of transport links, electricity supply, water supply, sewage or telecommunications services and they may therefore require resupply or in the worst case, evacuation.

Overland Refuge Areas

These are areas that other areas of the floodplain may be evacuated to, at least temporarily, but which are isolated from the edge of the floodplain by floodwaters and are therefore effectively flood islands or trapped perimeter areas. They should be categorised accordingly and these categories used to determine their vulnerability.

Note that Flood Management Communities identified as Overland Refuge Areas on Low Flood Island have been classified according to the SES Flow Chart for Flood Emergency Response Classification. These are areas where vehicular evacuation routes are inundated before residential areas of the Community.

9.3.3.1 Local Classification

Most of the flood affected properties in Gloucester are situated along Billabong Lane and Church Street. These remain flood free to the 20% AEP event but are inundated from the 10% AEP event. Evacuation from the eastern side of The Billabong can occur along the roads that run in an easterly direction to higher ground. The higher land in Gloucester remains flood free at the PMF event and so the area is best classified as a **Rising Road Access Area** for events of a 10% AEP magnitude or greater.

The caravan park is situated between the Gloucester River and The Billabong. It is largely not flood affected to the 20% AEP event, but from the 10% AEP event the potential evacuation routes become inundated. The caravan park itself becomes inundated from the 2% AEP event and is significantly flooded for the larger events. Due to the evacuation issues the caravan park is best classified as a **Low Flood Island** for events of a 10% AEP magnitude or greater. This classification also applies to other properties situated to the west of Billabong Lane.

The community of Barrington is largely flood free for the full range of design flood events. However, the Thunderbolts Way becomes inundated across the Barrington Flats and in Gloucester from the 10% AEP event. The community may become isolated for a few hours to a couple of days (dependent of event magnitude and duration) and so is best classified as a **High Flood Island**.

9.3.4 True Hazard Categorisation

The true hazard categorisation is typically based on the hydraulic hazard categorisation discussed in Section 8.5. However, it also takes into consideration aspects of the flood emergency response management. Given the relatively short warning time available, the potential for rapidly rising floodwaters and the occurrence of Low Flood Islands within sections of the floodplain, the provisional hazard has been modified to reclassify islands of Low Hazard as High Hazard areas. This is consistent with the approach adopted for the 2004 Gloucester Floodplain Management Study.

True hazard category mapping is included in the Mapping Compendium, and is presented for the 1% AEP events and PMF events.

10 Conclusions

The objective of the study was to undertake a detailed flood study of the Gloucester and Avon River catchments and establish models as necessary for design flood level prediction.

In completing the flood study, the following activities were undertaken:

- Collation of historical and recent flood information for the study area;
- Development of computer models to simulate hydrology and flood behaviour in the catchment;
- Calibration of the developed models using the available flood data, including the recent events of 2011 and 2013 and the historic events of 1929, 1956 and 1978;
- Prediction of design flood conditions in the catchment and production of design flood mapping series.

The study provides updated and more detailed flooding information to support the existing Gloucester Floodplain Management Study. As such some floodplain risk management considerations were included within this study.

The main departure of this study from the previous work is the significant reduction in flood level estimations for the more frequent flood events. This is primarily a function of the design rainfall depths which were adopted for the hydrologic modelling. This study included flood frequency analyses at the Forbesdale gauges on the Gloucester and Barrington Rivers, which determined that the more frequent flood events were significantly over estimated by the standard rainfall runoff approach.

The modelled flood level in Gloucester for the 1% AEP event is similar in this study to that of the previous modelling (and to that of the 1929 flood). This event is used as the basis for flood planning controls and so the updated flood mapping should provide a relative consistency with what has previously been used for these purposes.

As was determined through the previous studies, the majority of flood risk within Gloucester is associated with the commercial and residential properties situated between The Billabong and Church Street. There is limited flooding to other properties outside of this area except in the PMF. The caravan park requires evacuation prior to the onset of flooding as it is situated on an island that becomes isolated by floodwaters.

11 References

Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2004) *Climate Change in New South Wales Part 2: Projected changes in climate extremes.*

Department of Environment, Climate Change and Water (DECCW) (2007) *Floodplain Risk Management Guideline: Practical Consideration of Climate Change.*

NSW Department of Infrastructure, Planning and Natural Resources (DIPNR) (2005) *Floodplain Development Manual.*

Paterson Consultants (2004) *Gloucester Flood Study Supplementary Report*

Paterson Consultants (2004) *Gloucester Floodplain Management Study*

Appendix A Community Information Brochure and Questionnaire

What is the study about?

The main objective of the study is to characterise the flooding behaviour in the catchment describing in detail the potential flood inundation extents, peak water levels, depths and velocities across the floodplain for a range of flood magnitudes.

Detailed computer models are developed specifically for the catchment to simulate flood behaviour. Historical flood information such as rainfall records, peak water levels, flooded property details etc, are used to ensure the computer models are representative of the real catchment behaviour.

Flood maps across the catchment will be produced using the model results which will show the predicted extent of flooding.

The flood study results will be used to provide more effective flood planning in the catchment and will assist Councils in:

- Setting appropriate levels for future development control;
- Identifying potential works to reduce existing flooding; and
- Improving flood emergency response and recovery.

This project has been implemented through the Gloucester Water Study Project.

Want more information?

For further information about the Gloucester and Avon Rivers Flood Study, or to provide any information you feel is relevant to the study, please contact:

Gloucester Shire Council

Kate Johnson
Gloucester Shire Council
PO Box 11
Gloucester NSW 2422
Ph (02) 6538 5203
e: kate.johnson@gloucester.nsw.gov.au

BMT WBM

Mr Daniel Williams (Project Manager)
BMT WBM (Consultant)
Ph 4940 8882
e: *Daniel.Williams@bmtwbm.com.au*

We need your help!

Your information about previous flooding, including photographs and video, is highly valuable in understanding flooding behaviour and potential flood risk to residents.

You can help us by passing on information about flooding you may have experienced by completing the questionnaire enclosed with this brochure.

Please take a minute to fill in the questionnaire and return with any other information you feel relevant by 25th July 2014.

Gloucester and Avon Rivers Flood Study

Community Information Brochure

Denison Street, June 2011 Flood Event

Gloucester Shire Council

BMT WBM

Introduction

Gloucester Shire Council is carrying out a flood study to understand flood risks in the Gloucester and Avon Rivers catchment. This includes the Avon River floodplain, the town of Gloucester and the floodplains of the Barrington and Gloucester Rivers upstream to Forbesdale.

Gloucester Shire Council Floodplain Risk Management Committee will oversee the study, providing regular input and feedback on key outcomes. The Committee has a broad representation including Councillors, Council Staff, State Govt. representatives, stakeholder groups and community representatives.

BMT WBM, an independent company specialising in flooding and floodplain risk management, will undertake the study

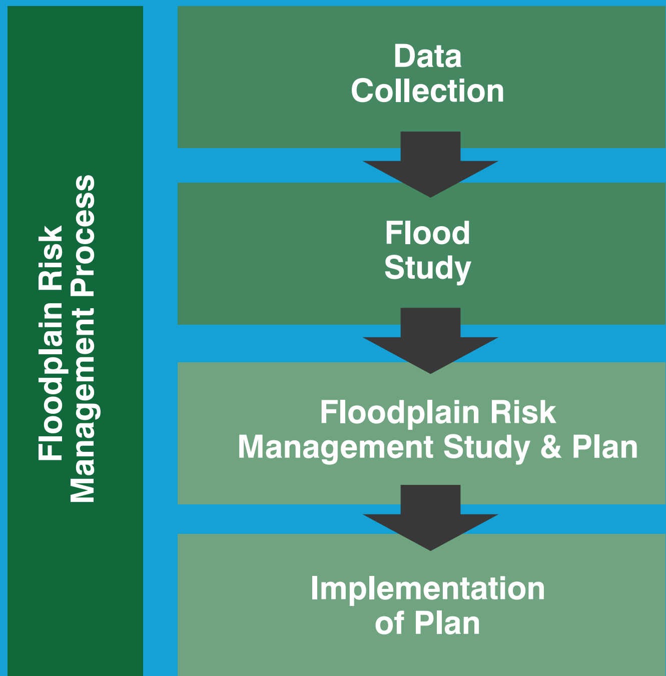
Barrington River

Why do we need a study?

The Gloucester and Avon Rivers catchment has a history of major flooding, including the significant events of 1929 and 1978 and more recently smaller events in 2011 and 2012.

In order to appropriately plan for future flood events and reduce the potential impacts of flooding on the community, we need to determine the nature and extent of the existing flooding problem across the catchment.

The study will identify existing flood risk within flood prone areas of the catchment including the main areas of existing development and help in Council's planning for the future.



The next stage of the floodplain risk management process is the assessment of a range options to manage these flood risks for existing and future development.

Community input and involvement

Community involvement in managing flood risks is essential to improve the decision making process, to identify local concerns and values, and to inform the community about the consequences of flooding and potential management options. The success of the flood planning in the Gloucester and Avon Rivers catchment hinges on the community's input and acceptance of the proposals.

There are a number of ways you can be involved in the study:

Please take a few minutes of your time to complete and return the questionnaire. This will greatly assist in collating people's knowledge and experience about previous flooding history and existing flood problem areas.

A community information session is planned at a later stage following completion of the modelling assessments to present study results and provide further opportunity for feedback from the community.

Thank you for taking the time to complete this questionnaire!

The questionnaire can be returned without a postage stamp or scanned and emailled to Daniel.Williams@bmtwbm.com.au. Flood photos and videos can also be sent to this email address. "Hard copies" of photos or VHS tapes can be posted to:

Daniel Williams
BMT WBM
126 Belford Street
Broadmeadow New South Wales 2292

BMT WBM will analyse the community responses and report back to Council. If you would like to have items returned please note this and the items will be returned at the conclusion of the study.

Fold Here

How to send back this questionnaire...

Please fold this questionnaire using the 'Fold Here' lines as a guide to form a business sized envelope with the address on the front and this text box on the back. Seal the folded pages with a piece of tape to help maintain privacy (but not so much tape that we can't open it) and then post it back.

Fold Here

Delivery Address:
PO Box 266
BROADMEADOW NSW 2292

No stamp required
if posted in Australia

BMT WBM Pty Ltd
Reply Paid 266
BROADMEADOW NSW 2292

Gloucester and Avon Rivers Flood Study

Gloucester and Avon Rivers Flood Study

Community Questionnaire

Gloucester Shire Council is completing a flood study for the Gloucester and Avon Rivers catchment. The flood study is the first step in assisting council to better understand, plan and manage the risk of flooding across the catchment.

The information that you provide in the following questionnaire will prove invaluable in the calibration of computer models that are being developed as part of the flood study. It will also provide Council with an understanding of existing flooding problems and areas where flood damage reduction measures should be investigated in the future.

The following questionnaire should only take around 10 minutes to complete. Try to answer as many questions as possible and give as much detail as possible (attach additional pages if necessary). Once complete, please return the questionnaires via email or mail (no postage stamp required) by 25th July 2014.

If you have any questions, require any further information or would like to contribute additional information to the study, please contact:

BMT WBM "Where will our knowledge take you?"

Daniel Williams
BMT WBM
126 Belford Street
Broadmeadow NSW 2292
(02) 4940 8882
Daniel.Williams@bmtwbm.com.au

Gloucester Shire Council

Kate Johnson
Gloucester Shire Council
PO Box 11
Gloucester NSW 2422
Ph (02) 6538 5203
e: kate.johnson@gloucester.nsw.gov.au

QUESTION 1 (OPTIONAL)

Can you please provide the following contact details in case we need to contact you for additional information?

Note that your personal information will remain confidential at all times and will not be published unless you give us permission to do so (refer to following question).

Name: ______________________ Phone Number: ______________________

Address: ______________________ email: ______________________

____

Do you give permission for your contact details to be published as part of the flood study?

☐ Yes ☐ No

BMT WBM "Where will our knowledge take you?" Gloucester Shire Council

QUESTION 2

How long have you lived and/or worked in the area?

At current address: ________________ Years __________ Months __________

In the general area: ________________ Years __________ Months __________

QUESTION 3

Have you been affected by flooding in the past?

☐ Yes ☐ No

If 'Yes', how have you been affected?

☐ Traffic was disrupted (please provide a description below if possible)

☐ My back/front yard was flooded (please provide a description below if possible)

☐ My house/business and its contents were flooded (please provide a description below if possible)

☐ Sewer or water was turned off at my property (please provide a description below if possible)

☐ Other (please provide a description below if possible)

Description: ____

QUESTION 4

Can you provide specific details of how high floodwaters reached?

☐ Yes ☐ No

If 'Yes', please give as much detail as possible (e.g., location, dates, times, description of water movement, depth of water, flood mark location, high water mark on building, level on flood depth indicator).

QUESTION 5

What do you think may have been the main source/cause of the flooding (e.g., creek banks overtopping, blockage of bridges)?

QUESTION 6

Did you keep any rainfall records during any past storm events, or do you know someone locally that does?

☐ Yes ☐ No

If 'Yes', can you please include a copy of the records or provide a description of the records below?

QUESTION 7

Are you concerned that your property could be flooded in the future?

☐ Yes ☐ No

If 'Yes', what makes you concerned?

QUESTION 8

Do you have any other comments or information that you think would be useful for this investigation?

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WINNER

BMT WBM

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